



Navigation Simulation Study, Mouth of the Colorado River, Matagorda, Texas

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Prepared for U.S. Army Engineer District, Galveston

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by Michelle M. Thevenot, Larry L. Daggett

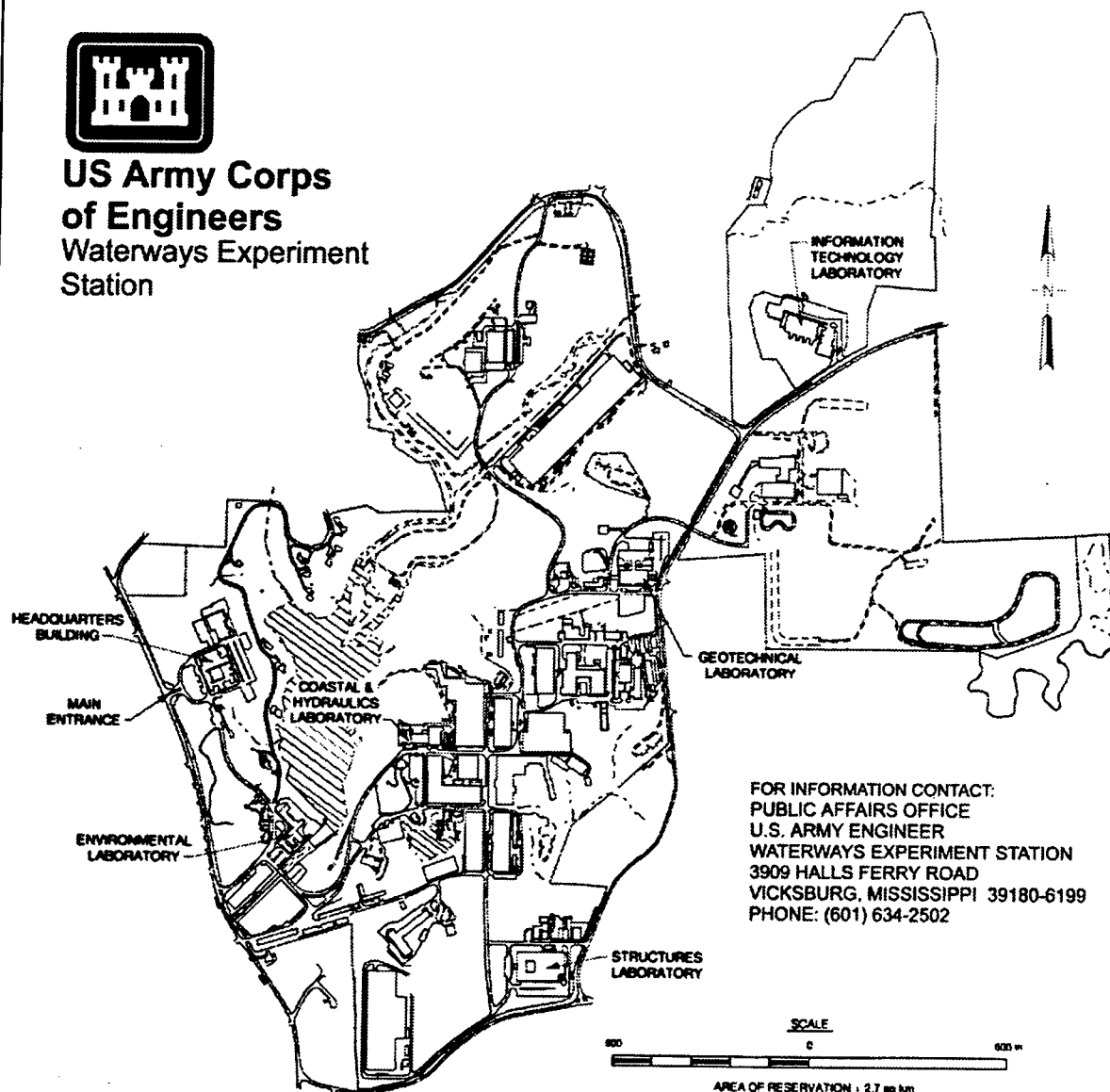
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Preface

This investigation was performed by the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Engineer District, Galveston (SWG). The study was conducted with the WES research Ship and Tow Simulator (SATS). Authority was given by SWG. SWG provided the essential field and model data required.

The investigation was conducted by Ms. Michelle M. Thevenot and Dr. Larry L. Daggett of the Navigation Branch, Waterways Division, Hydraulics Laboratory, under the general supervision of Messrs. Frank A. Herrmann, Jr., Director of the Hydraulics Laboratory; R. A. Sager, Assistant Director, Hydraulics Laboratory; and M. B. Boyd, Chief of the Waterways Division.

Acknowledgement is made to Mr. Edward A. Reindl, Jr., Engineering Division, SWG, for cooperation and assistance at various times throughout the investigation. Special thanks should go to the Texas Waterways Operators (TWO's) for furnishing professional pilots to steer the towboats during the simulator tests on the WES tow simulator.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Preconstruction Conditions

The preconstruction Colorado River flowed into the Gulf of Mexico, crossing the Gulf Intracoastal Waterway (GIWW) near Matagorda, TX (Figure 1). Two locks, one on each side of the Colorado River crossing of the GIWW, are provided to help control flows into the GIWW and improve navigation (Figure 2). The two identical lock chambers are 1,200 ft¹ long, 75 ft wide, and 15 ft below mean low tide (mlt);² the GIWW is 12 ft deep and 125 ft wide. Navigation becomes difficult when the Colorado River flows are high during the spring rainy season. Tows transiting the GIWW in the study area usually include one to four barges, varying in length from about 400 ft up to 1,100 ft long, 52 ft or 54 ft wide, and loaded to 9-ft draft. The average tow consists of two to three barges and is approximately 600-700 ft long. When the Colorado River flows are high, loaded barges are "tripped" one at a time across the river because of the strong crosscurrents.

Improvement Project

A project to divert the freshwater riverflows into Matagorda Bay is presently under construction. Its main purpose is to improve the biologic productivity of the bay. Figure 1 shows the principal features of the project. The diversion channel has been constructed from the GIWW to Matagorda Bay and the temporary "plug" blocking the flow has been removed. Two jetties to stabilize the mouth of the present Colorado River are in place and some dredging to open up sand deposits at the mouth is under way.

The project includes a diversion dam to be located on the natural Colorado River channel and a navigation bypass channel to allow small craft access from the GIWW to the Gulf. The navigation bypass channel outlet will join the GIWW between the eastern lock gates and a floating pontoon bridge on

¹ A table of factors for converting non-SI units of measure to SI units is found on page vi.

² All elevations (el) cited herein, unless otherwise noted, are in feet referred to mean low tide (mlt).

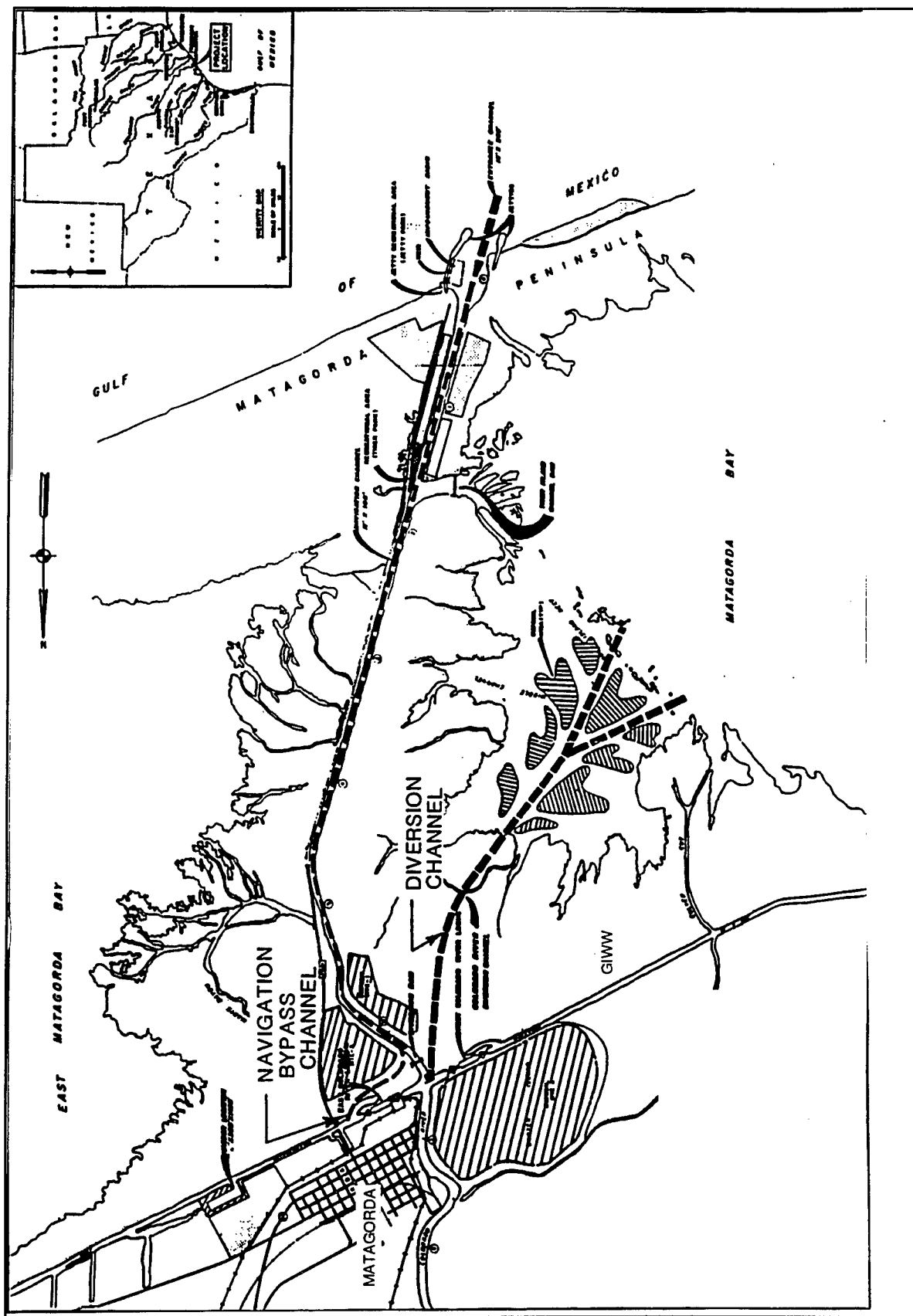


Figure 1. Location and vicinity map

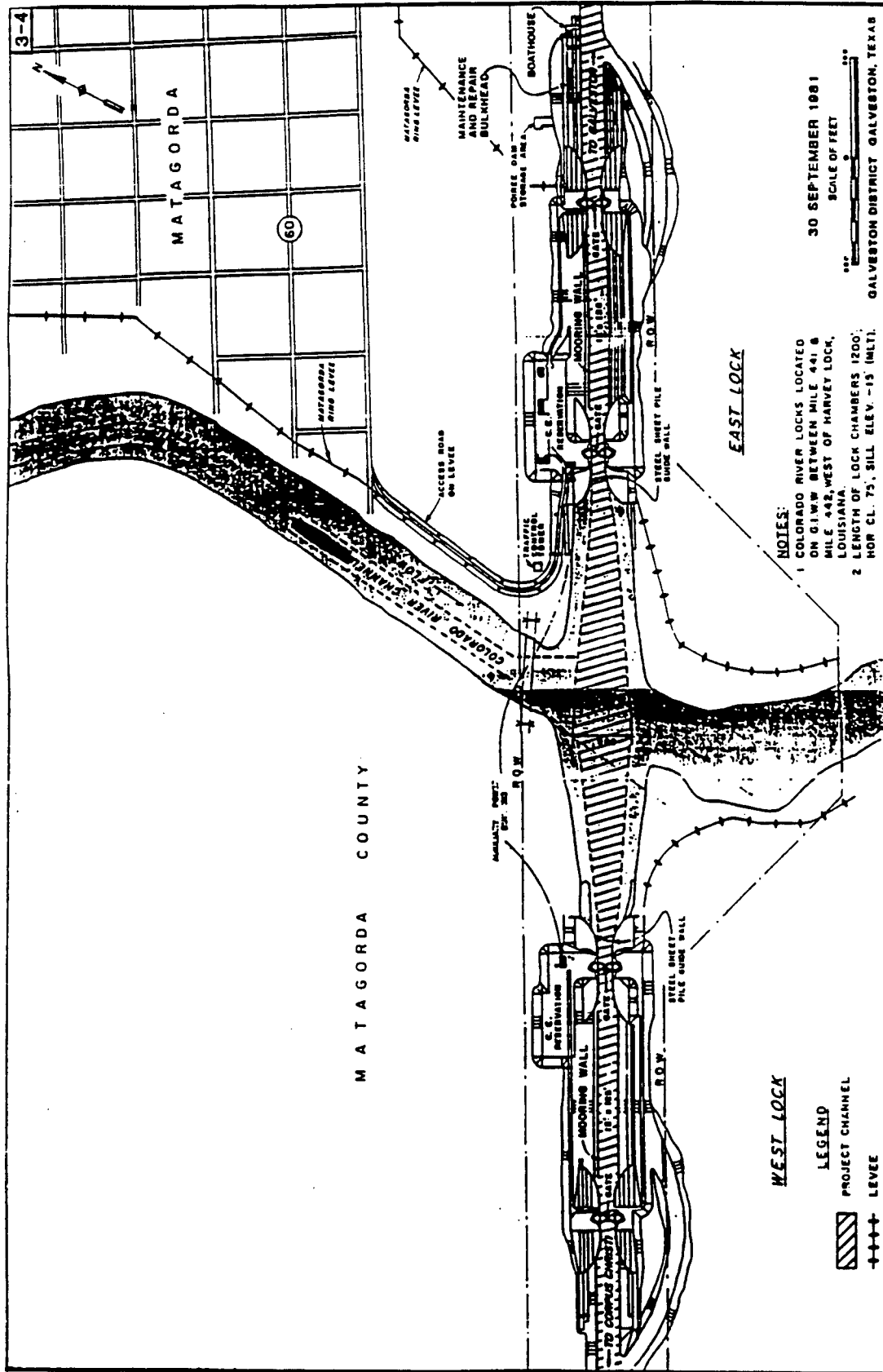


Figure 2. Colorado River locks

Route 2031 (Figure 3). Neither the diversion dam nor the navigation bypass channel has been constructed. Construction of this part of the project is being delayed pending an analysis of the potential impacts of the project on navigation in the area.

Concerns have been expressed by the towing industry about the proposed project. Their concerns include the following:

- a.* The new diversion channel could increase the adverse effects of the high crosscurrents from the Colorado River.
- b.* Tidal currents from the navigation bypass channel could have negative impacts on GIWW traffic. The latter concern is the most serious and is due to a possible cross flow into the GIWW which could affect transiting tows between the east lock gates and the floating pontoon bridge. Control of the tows in this area is expected to become very difficult when tidal currents are strong, which could occur during every 28-day tidal cycle.

Study Purpose

The purpose of the study was to determine three things:

- a.* If diversion of the riverflow into the channel to Matagorda Bay will have a negative impact on tows crossing the Colorado River between the locks.
- b.* Tidal flows that may cause navigation problems for GIWW traffic in the vicinity of the navigation bypass channel.
- c.* At what frequency critical flow conditions will occur and to develop operating procedures to minimize the impacts of these critical flows.

The study was conducted on the Ship and Tow Simulator at the U.S. Army Engineer Waterways Experiment Station (WES).

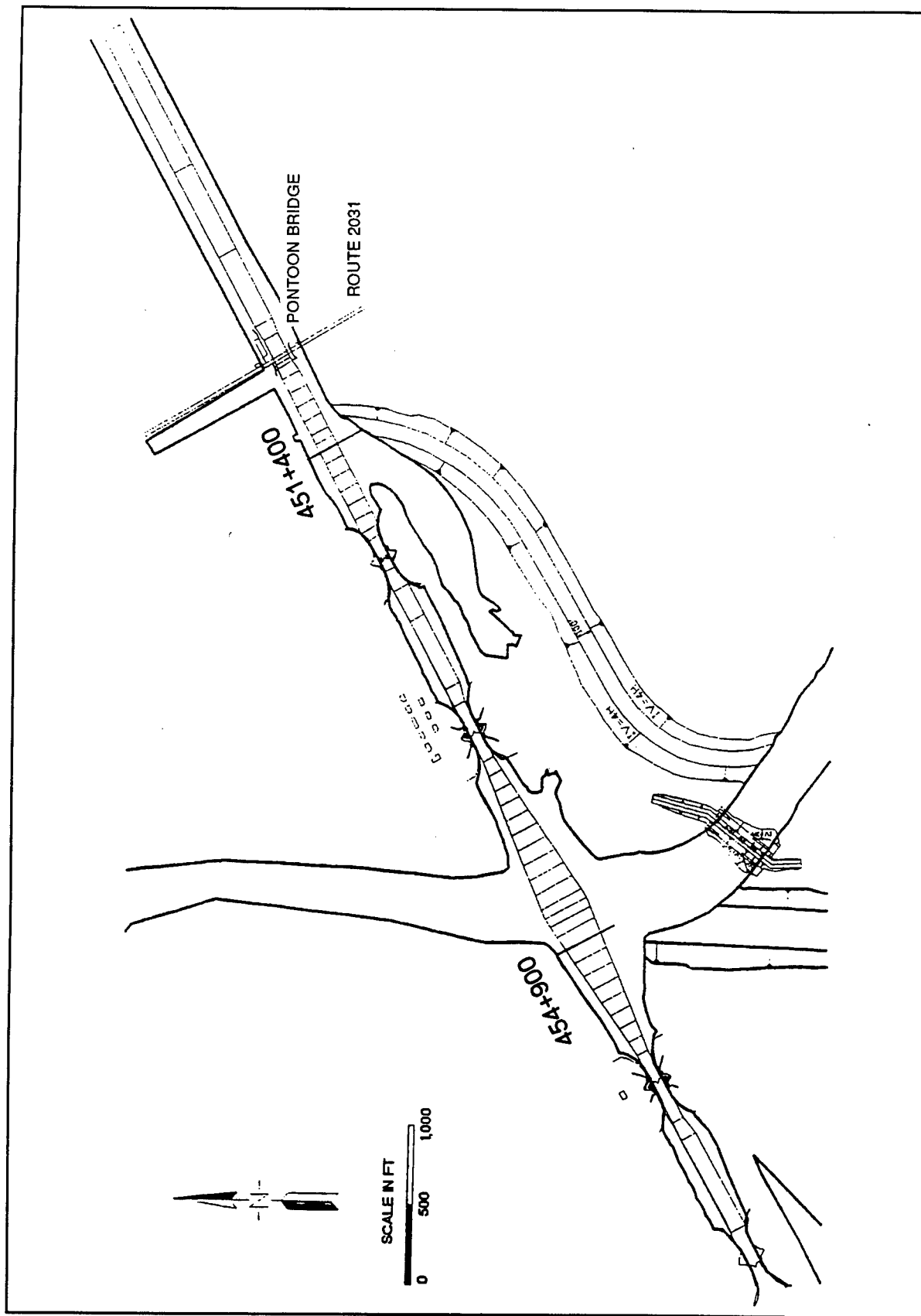


Figure 3. Simulated GIWW channel

2 Data Development

In order to simulate the study area on the ship simulator, it is necessary to develop information relative to five types of input data:

- a.* The channel database contains dimensions for the existing channel. It includes the channel cross sections, angle of side slopes, overbank depth, and autopilot track-line and speed definition.
- b.* The visual scene database comprises principal features of the simulated area, including the aids to navigation, structures, and loading facilities.
- c.* The radar database contains the features for the plan view of the study areas.
- d.* The ship data file contains characteristics and hydrodynamic coefficients for the experiment vessels.
- e.* The current pattern data in the channel include the magnitude and direction of the current for each cross section defined in the channel database.

Channel Development

The information used to develop the channel database came from construction drawings furnished by the U.S. Army Engineer District, Galveston. This was the latest information available concerning the dimensions of the channel. Texas planar coordinates were used for the definition of the data.

The simulated GIWW channel, which begins 1 mile east of the Route 2031 pontoon bridge and ends at the west gate of the west lock chamber, has 51 cross sections. Figure 3 shows the defined GIWW channel. Station 451+400, located between the pontoon bridge and the east gate of the east lock chamber, is a typical cross section in this area. This cross section is shown in Figure 4. The lower plot shows the cross section to scale; the upper plot has an exaggerated vertical scale so that differences are more apparent. Station 454+900 is located between the lock chambers on the Colorado River as shown in Figure 3. This cross section, which is typical for this area, is shown

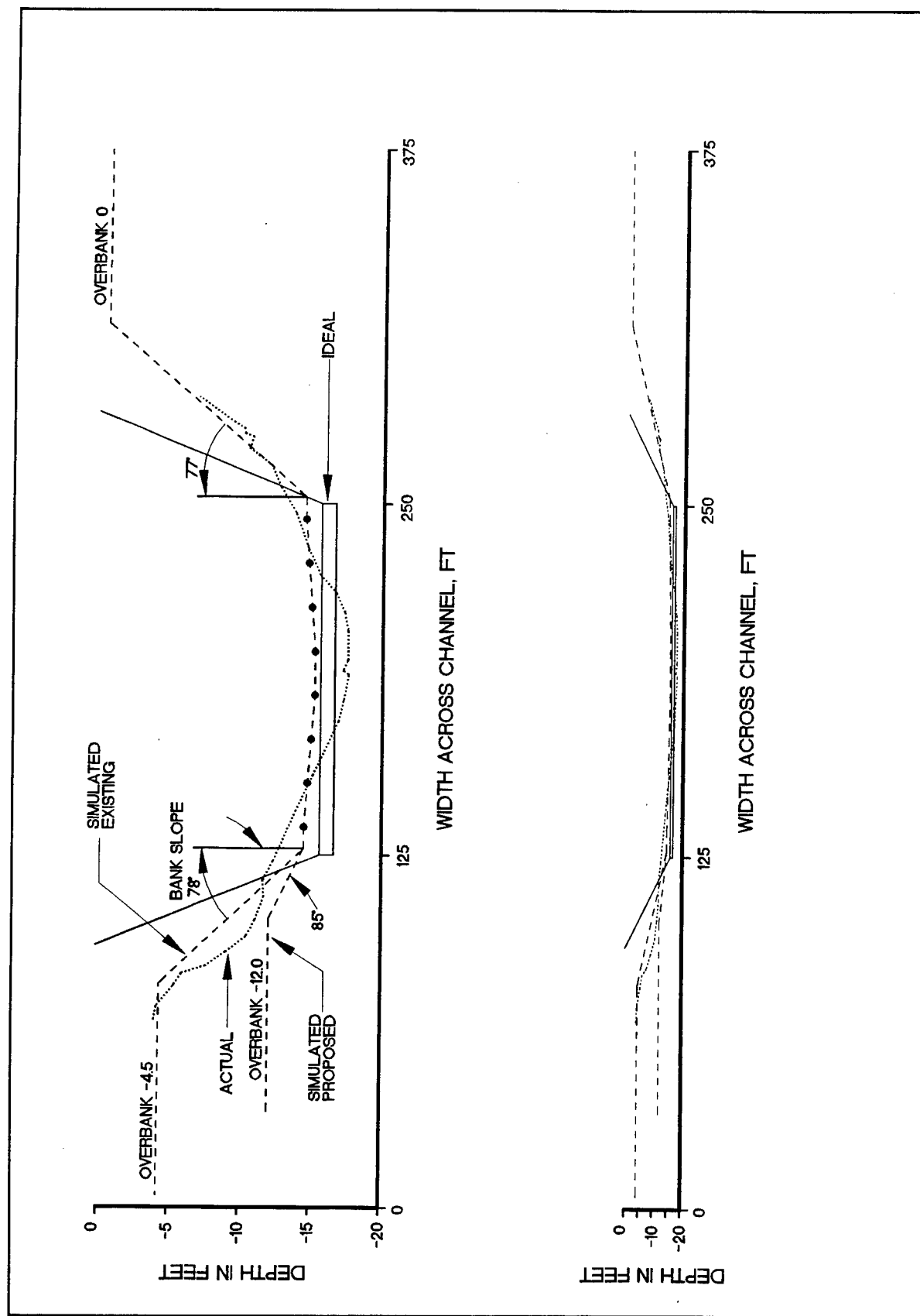


Figure 4. Channel cross section, station 451 + 400

in Figure 5. The cross section plots, Figures 4 and 5, show the idealized channel, the simulated channel, and the actual channel. Station 451+400 also has a simulated proposed channel. Where the navigation bypass channel intersects the GIWW (Figure 3), the bottom elevation was input at -12. The change in bank condition between existing and proposed simulated channels is shown in Figure 4.

Cross sections were placed at each surveyed cross section. It was determined that the currents were not adequately reproduced, so cross sections were added where important changes in magnitude and directions occurred. The tow simulator model allows eight equally spaced points to define each cross section. At each of these points, a current magnitude and direction as well as a depth are required. These data were extracted from the output of the mathematical model study.¹ For each cross section, right and left bank slopes and overbank depths are required. These data were obtained from the cross-section data provided by the Galveston District for use in the main program for calculating bank suction forces. Figures 4 and 5 show the eight points, the bank slopes, and the overbank depths for stations 451+400 and 454+900, respectively.

Visual Scene

The visual scene database was created from the same maps and charts used to develop the channel database. Areal photographs, still photographs, and pilot's comments obtained aboard a towboat during a reconnaissance trip to the mouth of the Colorado River constitute other sources of information for the scene. These allowed inclusion of the significant physical features the pilots use for informal ranges and location sightings.

All aids to navigation such as buoys, channel markers, docks, and buildings are included in the visual scene. The visual scene requires definition in three dimensions: north-south, east-west, and vertical elevation. Again the state planar coordinate system was used. As the ship progresses through the channel, the three-dimensional picture is constantly transformed into a two-dimensional perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the relative direction and position on the bridge for viewing. The graphics hardware used for the mouth of the Colorado River project, Silicon Graphics Iris 2300 and 2400, are connected to the VAX 11/750, which computes the forces on the tow and the tow response to obtain information for updating the

¹ Larry M. Hauck. (1992). "Hydrodynamics at mouth of Colorado River, Texas, Project; numerical model investigation," Technical Report HL-92-11, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

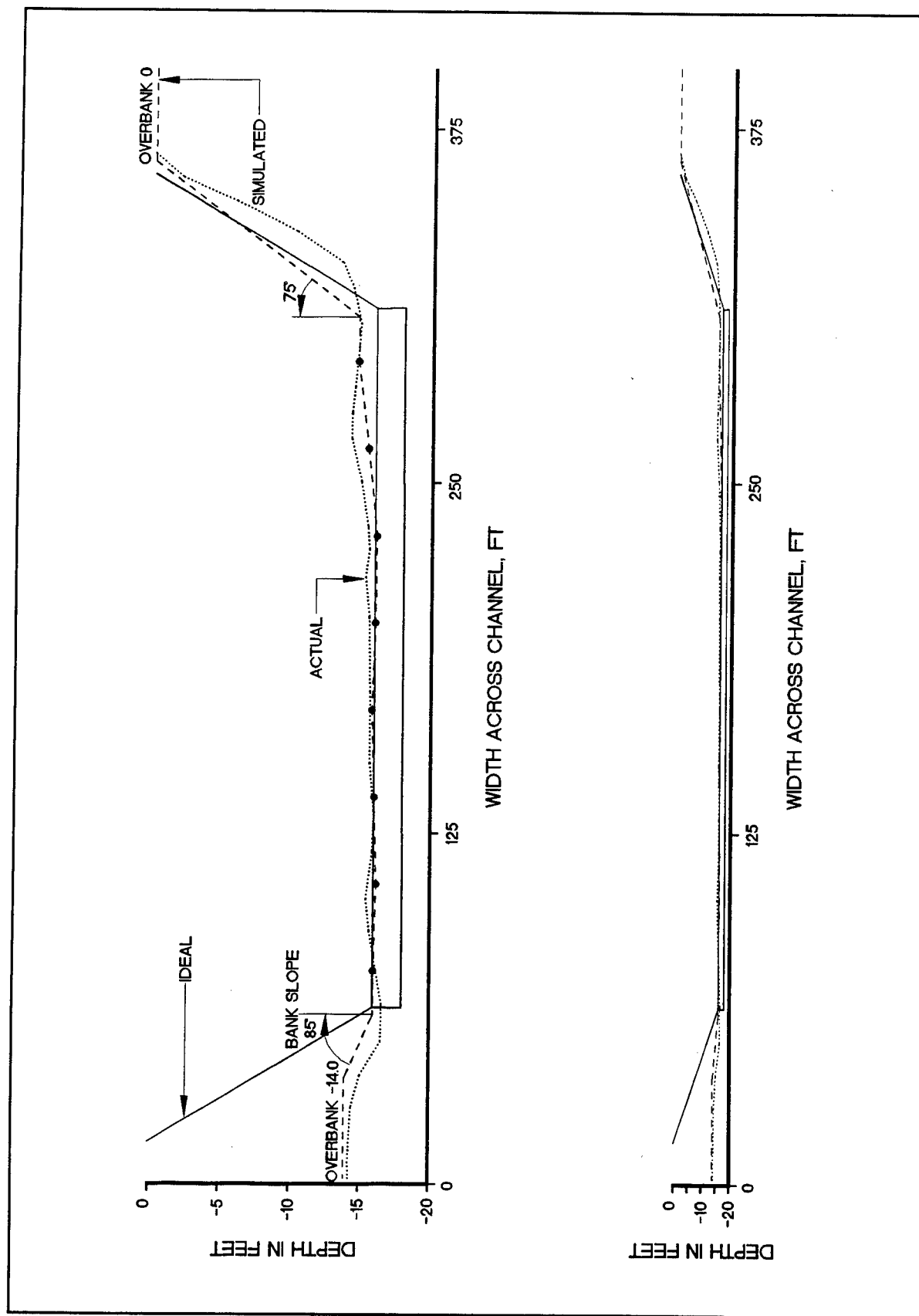


Figure 5. Channel cross section, station 454 + 900

viewing position and orientation of the ship. Also the viewing angle is passed to the graphics computers for the look-around feature on the simulator console. This feature enables the pilots to look at objects outside of the straight-ahead view, which encompasses only a 40-deg field of view. This feature simulates the pilot's ability to see any object with a turn of his head. The pilot's position on the bridge can also be changed from the center of the bridge to the edge of the tow at the bridge wing or anywhere in between to obtain a better view.

It should be noted that the creation of a scenario for the project area is very demanding in terms of engineering judgment. The goal of the scenario is to provide all the required data without excessive visual clutter, bearing in mind the finite memory storage and computational resources available.

Radar

The radar database is used by two personal computers to generate a simulated radar for use by the experiment pilots. The radar database contains x- and y-coordinates that define the border between land and water. The file also contains coordinates for any major physical feature deemed important such as buildings, bridges, docks, locks, and aids to navigation. In short, these data define what a pilot would actually see on a shipboard radar. The radar image is a continuously updated view of the vessel's position relative to the surrounding area. Three different scales were programmed to allow the pilot to choose which scale he preferred.

Current

A current database contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the channel.

Current data used in the simulation were obtained from a TABS-2 mathematical current model developed at WES¹. This model was run using steady-state conditions. A nominal or representative velocity was determined at a cross section in the bypass channel south of the GIWW and in the Colorado River upstream of the intersection. These data were later compared to and revised based on hydrodynamic runs of the same conditions. Both the steady-state and hydrodynamic models were adjusted to field data obtained as part of the study. Figures 6 and 7 show an example of the current data obtained from the TABS-2 model and the corresponding current data implemented on the simulator, respectively, for the river intersection. Figures 8 and 9 show similar plots for the bypass area. Velocity magnitudes were adjusted.

¹ Hauck, op. cit.

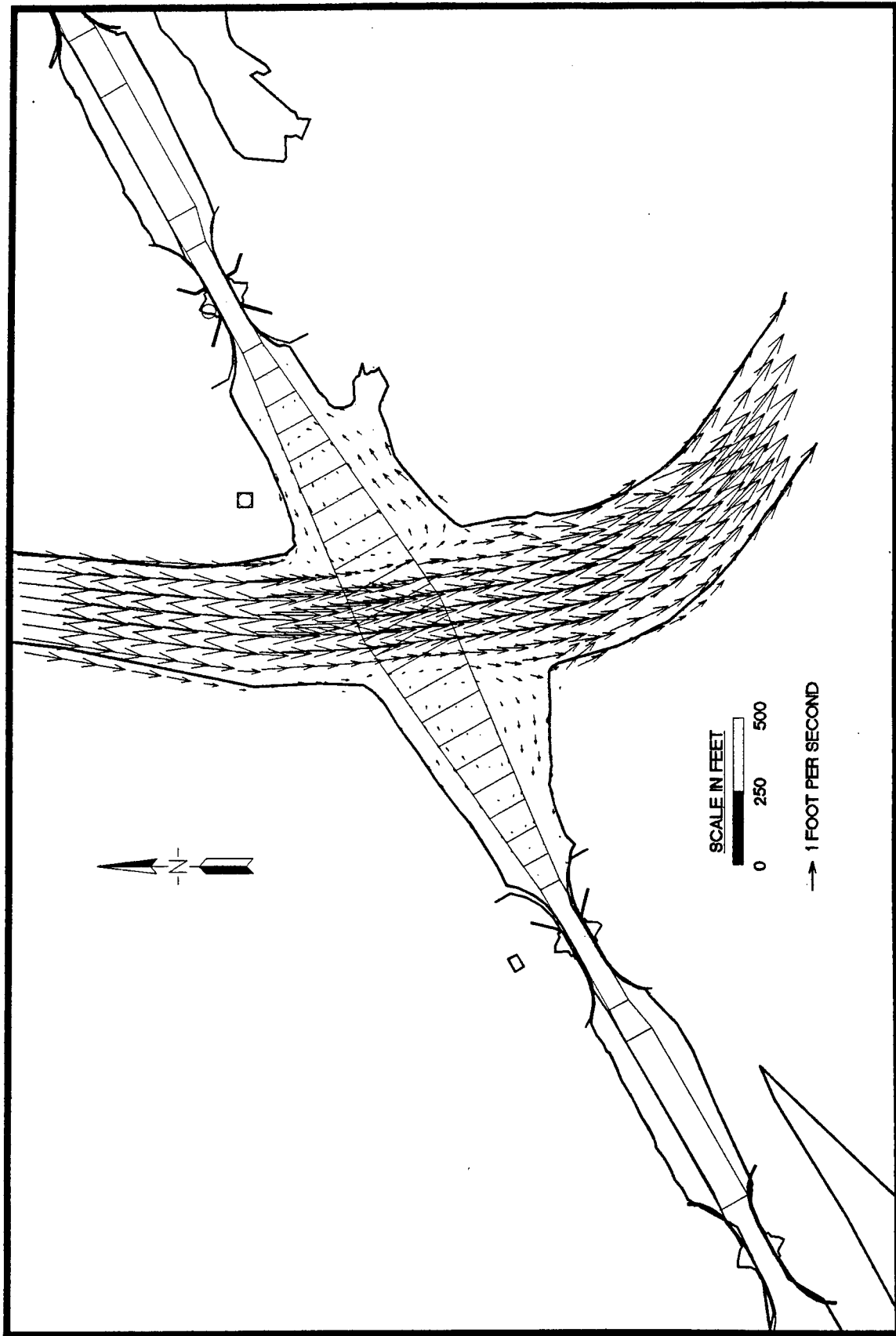


Figure 6. TABS-2 current data, river intersection, magnitude 2.0 fps

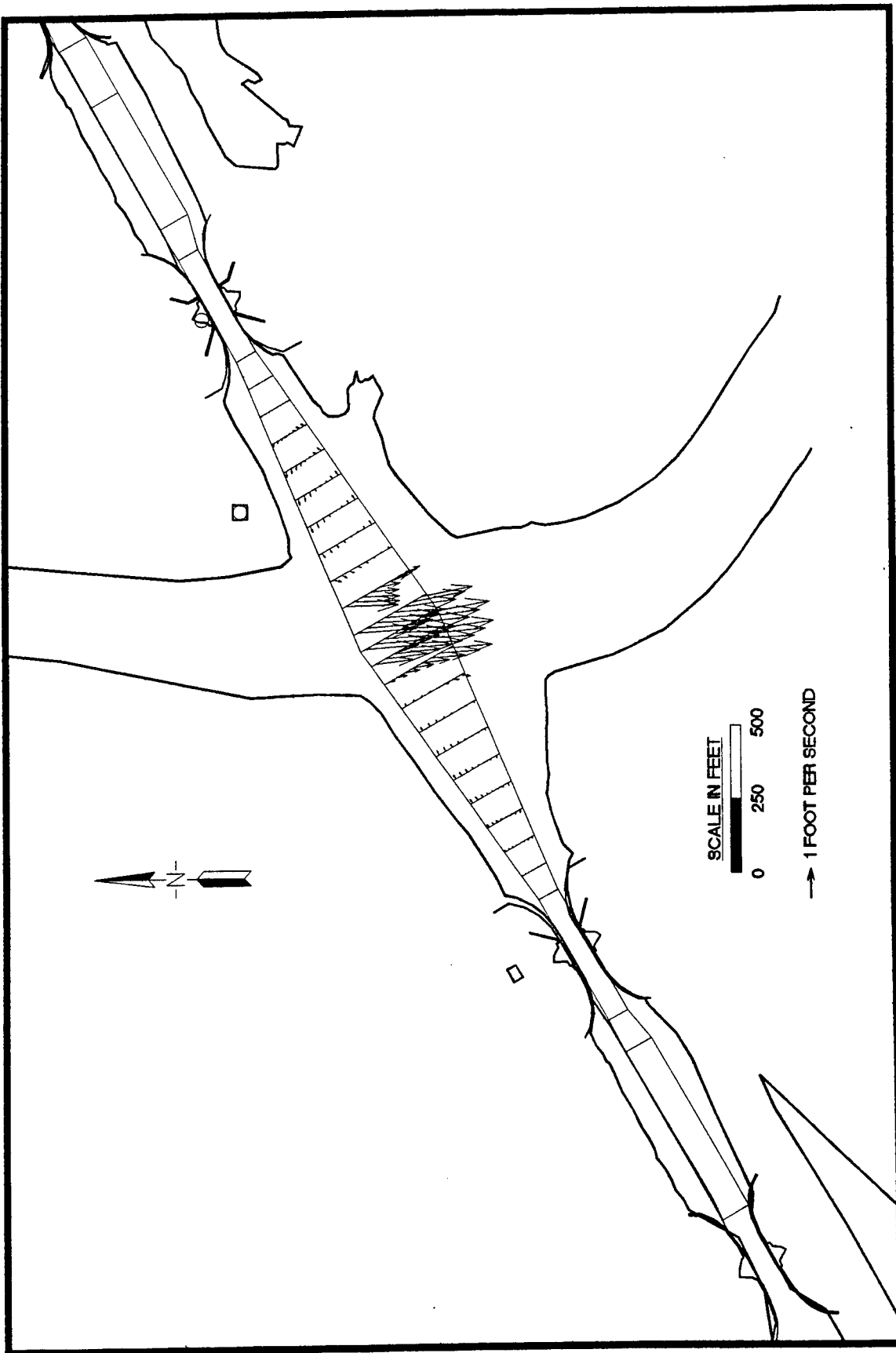


Figure 7. Simulator current data, river intersection, magnitude 2.0 fps

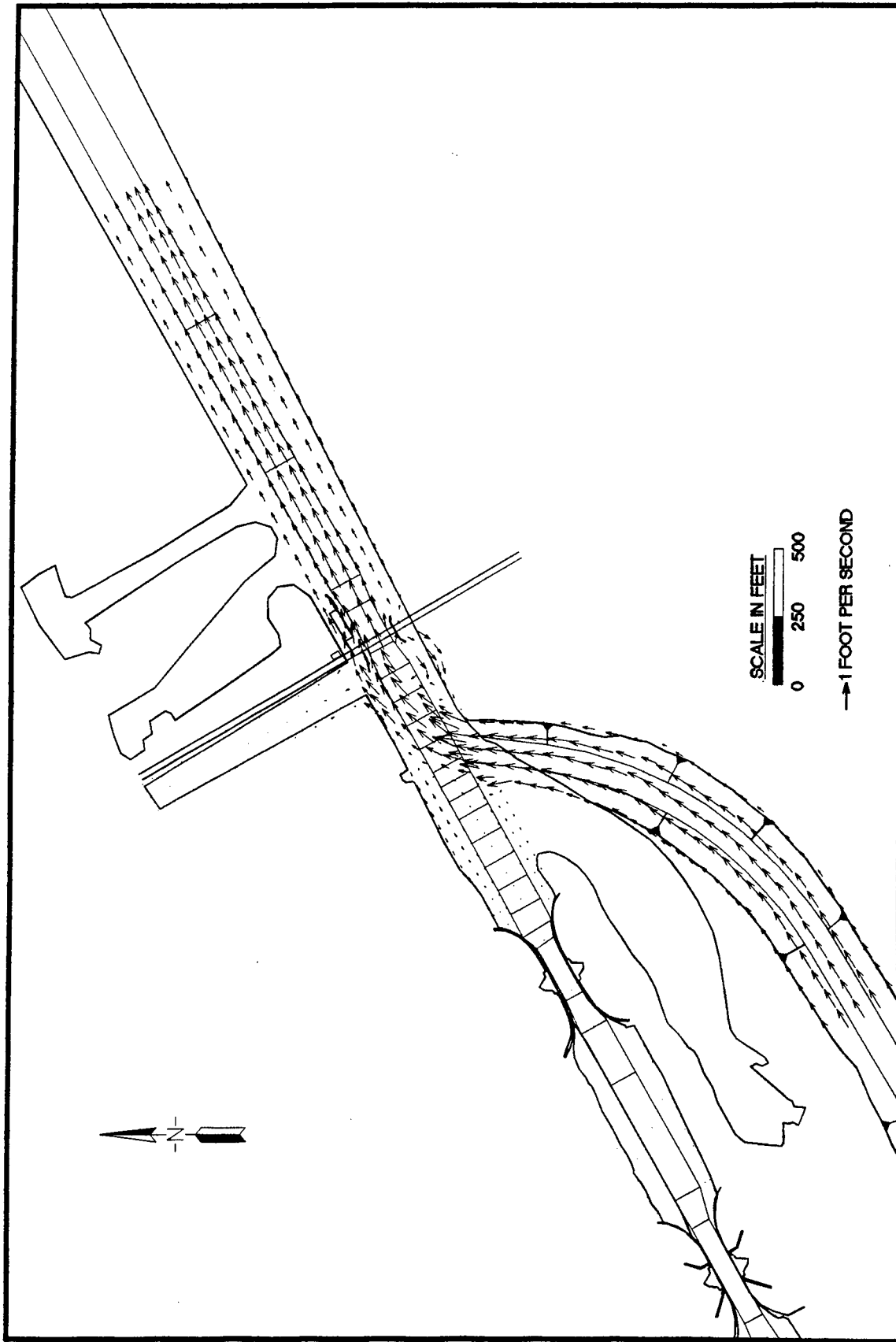


Figure 8. TABS-2 current data, bypass area, magnitude 1.0 fps

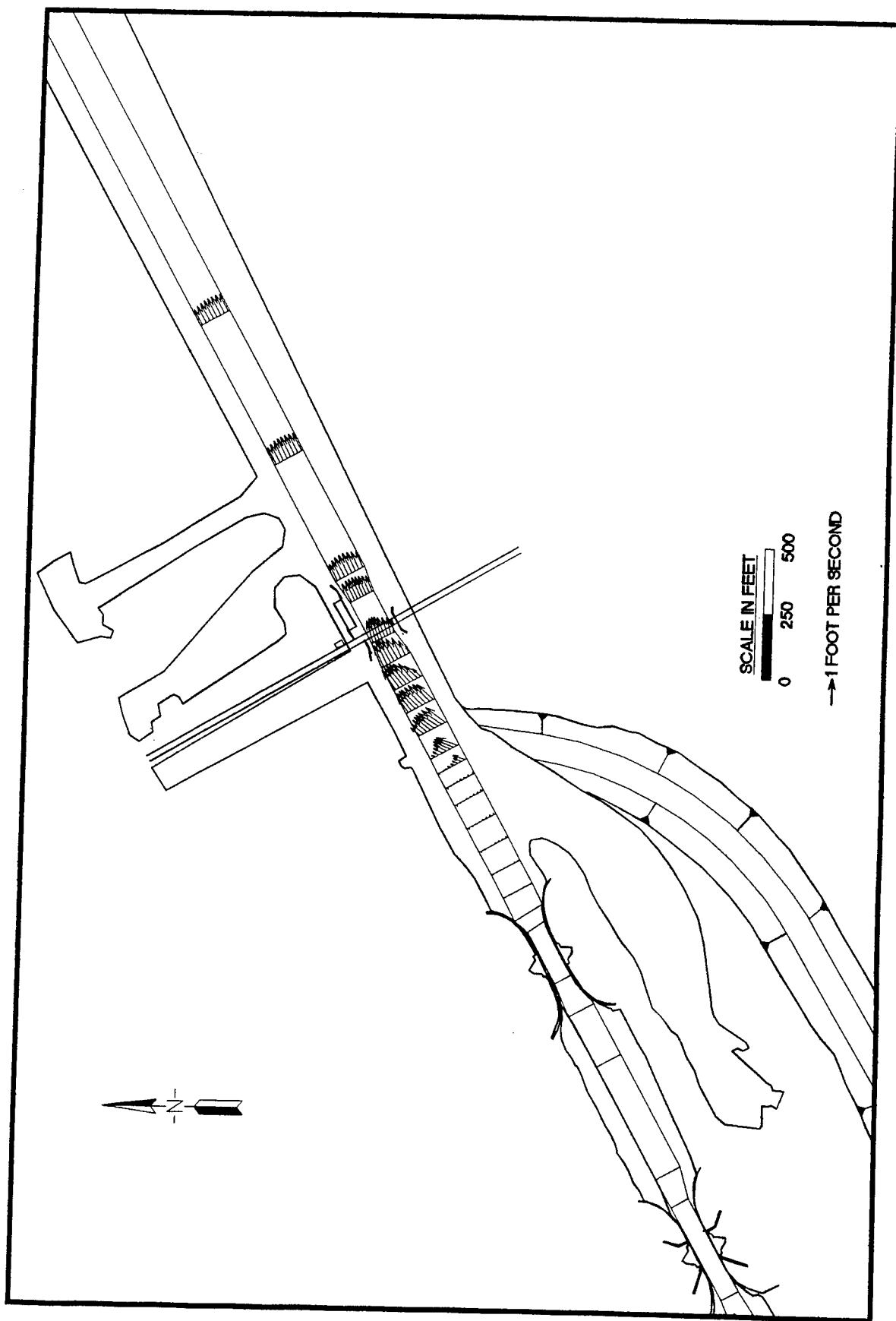


Figure 9. Simulator current data, bypass area, magnitude 1.0 fps

Test Ship

The ship database consists of the ship characteristics and coefficients used in the hydrodynamic program for calculating forces on the tows used in the experiment. In addition, the flotilla would also be seen in the visual scene by the pilot from the bridge. Therefore, a visual image of the flotilla had to be created.

Three tow configurations were used in the simulations.¹ A four-barge tow represented the maximum size vessel that would navigate the GIWW. It was 1,169 ft long with a 54-ft beam and 9-ft draft. The two-barge tow, which was 655 ft long and 54 ft wide and had a 9-ft draft, was an average size tow in this area. The single-barge tow was used because this is the configuration tripped across the river during high riverflows. The tripping procedure will include the bypass channel when it is constructed since the waiting tows are tied to moorings past the Route 2031 bridge when tripping. This tow was 355 ft long with a beam of 54 ft and a 8-ft draft.

¹ V. Ankudinov. (1990). "Hydrodynamic and mathematical models for ship maneuvering simulations of three tow configurations in deep water and restricted water depth conditions," Technical Report 90022.0123-1, performed by Tracor Hydronautics, Inc., Laurel, MD, for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

3 Navigation Study

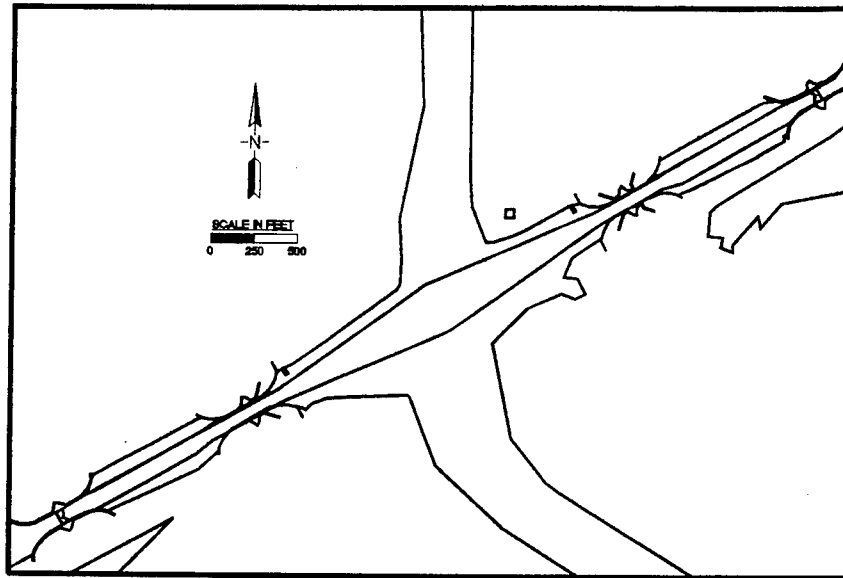
Test Conditions

The simulation study was designed to determine the maximum current velocities through which the tows could successfully pass the river diversion and the new bypass channel. Figure 10 shows the two river intersections that were tested. Figure 10a is the preconstruction river intersection and Figure 10b shows the postconstruction river intersection. Figure 11 illustrates the four alignments tested in the area of the bypass channel. Figure 11a illustrates the existing condition with no bypass cut. Figure 11b shows Plan 1, the design proposed by the District in the project's General Design Memorandum (GDM)¹. Figure 11c is Plan 2, a design suggested by the users of the GIWW in which the bypass intersects with the GIWW at an angle such that the currents are more aligned with the GIWW navigation channel. Figure 11d shows Plan 3, an alternative that was designed to decrease current velocities by increasing the width of the channel.

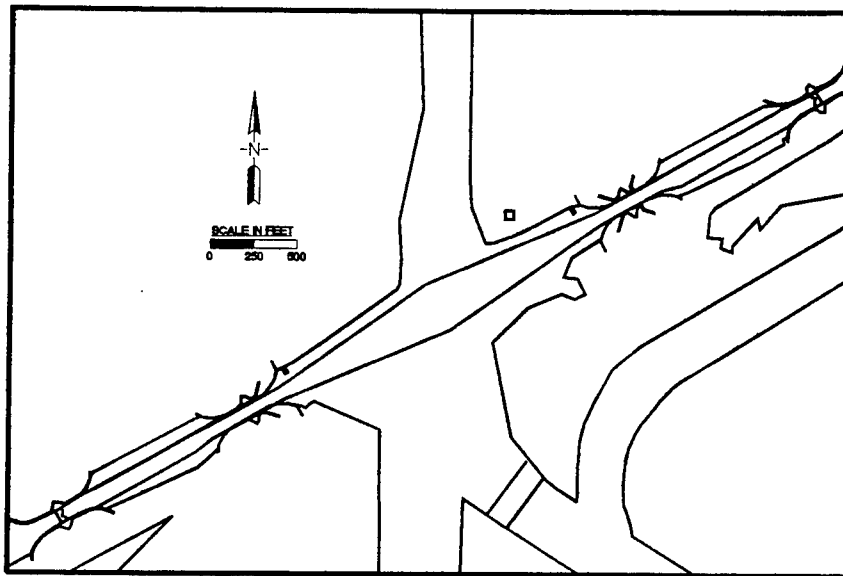
Fifty-four conditions were tested to determine the maximum current velocity for safe operation. A total of 370 runs were made in 99 different experiment combinations. These combinations are listed in Tables 1 and 2. Table 1 shows the experiment runs made of the river intersection (Figure 10), and Table 2 lists the experiment runs through the proposed bypass area (Figure 11).

For the river intersection, eastbound runs began as though the tow was tied to the west lock mooring wall, i.e., no headway and a heading of 60 deg. The towboat captain was to proceed across the river and stop in the east lock chamber. It was assumed that tows would lock through each time entering a lock, since the slow tow speed would result in testing the worst case for operating the tow. If the gates were opened, currents could possibly align more perpendicularly to the channel, resulting in more severe conditions. The westbound runs started at the east lock with a heading of 240 deg and no headway and proceeded across the river into the west lock. For the bypass

¹ U.S. Army Engineer District, Galveston. 1981 (March). "Mouth of Colorado River, Texas Phase I General Design Memorandum and EIS," Galveston, Texas.



A. PRECONSTRUCTION RIVER



B. POSTCONSTRUCTION RIVER

Figure 10. River intersections tested

Table 1
River Intersection Experiment Conditions

Experiment Condition	Channel ¹	Direction	Tow Configuration	Current		Captains						Total Runs Executed ²
				Direction	Magnitude fps	A	C	D	E	F	G	
1	DE	Westbound	Single barge	Ebb	7.5	1	1	1	1	1	1	6
					4.5	1	1	1	1	1	1	6
2	DE	Eastbound	Single barge	Ebb	7.5	0	1	0	0	1	1	3
					4.5	1	1	0	0	1	1	4
					3.5	1	1	0	0	0	0	2
					3.0	0	1	0	0	0	0	1
3	DE	Westbound	Two barge	Ebb	2.5	1	1	1	1	1	1	6
4	DE	Eastbound	Two barge	Ebb	2.5	1	1	1	1	1	1	6
					2.0	1	1	1	1	1	0	5
5	DE	Westbound	Four barge	Ebb	2.5	1	1	1	1	0	1	5
					2.0	0	1	0	0	0	0	1
6	DE	Eastbound	Four barge	Ebb	2.5	1	1	1	1	1	1	6
					2.0	1	1	0	0	0	0	2
7	D1	Westbound	Single barge	Ebb	7.5	1	1	1	1	0	0	4
					4.5	1	1	1	1	1	1	6
					3.5	0	0	1	1	0	0	2
					3.0	0	0	1	1	0	0	2
					1.5	0	0	1	1	0	0	2
8	D1	Eastbound	Single barge	Ebb	7.5	1	1	0	0	1	1	4
					4.5	1	1	0	0	1	1	4
					3.5	1	1	0	0	1	0	3
					3.0	1	0	0	0	0	0	1
9	D1	Westbound	Two barge	Ebb	2.5	1	1	1	0	1	1	5
					2.0	0	0	0	0	1	0	1
10	D1	Eastbound	Two barge	Ebb	2.5	1	1	1	1	1	1	6
					2.0	0	1	0	0	1	1	3
11	D1	Westbound	Four barge	Ebb	2.5	1	1	1	1	1	1	6
					2.0	1	1	0	0	0	0	2
12	D1	Eastbound	Four barge	Ebb	2.5	1	1	1	1	1	10	6
					2.0	0	1	1	0	0		2
												112

¹DE - Preconstruction River Intersection.

D1 - Postconstruction River Intersection.

²These numbers do not indicate successful runs but the total number of runs conducted at that condition. If the pilots were successful, then they did not go on to the next lower velocity. Therefore, the difference between the higher velocity runs and the lower velocity runs indicates the number of successful runs, e.g., for Condition 2, 4 - 2 at 4.5 and 3.5 = 2 successful runs at 4.5.

Table 2
Bypass Channel Experiment Conditions

Experiment Condition	Channel ¹	Direction	Tow Configuration	Current		Captains						Total Runs Executed
				Direction	Magnitude fps	A	C	D	E	F	G	
1	BE	Eastbound	Single barge		0.00	1	1	0.0	0.00	1	1	4
2	BE	Westbound	Single barge		0.00	1	1	0.0	0.00	1	1	4
3	BE	Eastbound	Two barge		0.00	1	1	0.0	0.00	1	1	4
4	BE	Westbound	Two barge		0.00	1	1	1	1	1	1	6
5	BE	Eastbound	Four barge		0.00	1	1	1	1	1	1	6
6	BE	Westbound	Four barge		0.00	1	1	0.0	0.00	1	1	4
7	BE	Eastbound	Single barge	Ebb	6.0	1	1	0.0	0.00	0.0	0.0	2
8	B1	Westbound	Single barge	Ebb	6.0	1	1	1	1	0.0	0.0	4
					4.5	1	1	1	1			4
					3.0	0	1	1	0			2
9	B1	Eastbound	Single barge	Flood	6.0	1	1	0.0	0.00	1	1	4
					4.5	1	1			1	1	4
10	B1	Westbound	Single barge	Flood	6.0	1	1	0	1	1	1	5
					4.5	1	1	1	0	0	0	3
					3.0	1	1	0	0	0	0	2
11	B1	Eastbound	Two barge	Ebb	4.0	1	1	0.0	0.00	0.0	0.0	2
12	B1	Westbound	Two barge	Ebb	4.0	1	1	1	1	0.0	0.0	4
					3.0	0	0	1	1			2
13	B1	Eastbound	Two barge	Flood	4.0	1	1	1	1	1	1	6
					3.0	1	1	0	0	0	0	2
					2.0	1	1	0	0	0	0	2
14	B1	Westbound	Two barge	Flood	4.0	1	1	0.0	0.00	0.0	0.0	2
					3.0	1	1					2
					2.0	1	1					2
15	B1	Eastbound	Four barge	Ebb	4.0	1	1	1	0.00	0.0	0.0	3
16	B1	Westbound	Four barge	Ebb	4.0	1	1	1	1	0.0	0.0	4
					3.0	1	1	0	0			2
					2.0	1	1	0	0			2
17	B1	Eastbound	Four barge	Flood	4.0	1	1	1	1	1	1	6
					3.0	1	1	1	1	0	0	4
					2.0	1	1	0	0	0	0	2
18	B1	Westbound	Four barge	Flood	4.0	1	1	0	0	1	1	4
					3.0	1	1	1	1	1	1	6
					2.0	1	1	0	0	0	0	2

(Continued)

¹ BE = existing condition.
B1 = Plan 1.
B2 = Plan 2.
B3 = Plan 3.

Table 2 (Concluded)

Experiment Condition	Channel	Direction	Tow Configuration	Current		Captains						Total Runs Executed
				Direction	Magnitude fps	A	C	D	E	F	G	
19	B2	Eastbound	Single barge	Ebb	6.0	1	1	0.0	0.00	0.0	0.0	2
20	B2	Westbound	Single Barge	Ebb	6.0	1	1	1	1	1	1	6
21	B2	Eastbound	Single barge	Flood	6.0	1	1	1	1	1	1	6
22	B2	Westbound	Single barge	Flood	6.0	1	1	1	1	1	1	6
23	B2	Eastbound	Two barge	Ebb	6.0	1	1	0.0	0.00	0.0	0.0	2
24	B2	Westbound	Two barge	Ebb	4.0	1	1	1	1	1	1	6
25	B2	Eastbound	Two barge	Flood	4.0	1	1	0.0	0.00	1	1	4
26	B2	Westbound	Two barge	Flood	4.0	1	1	1	1	1	1	6
					3.0	1	1	0	0	0	0	2
					2.0	1	1	0	0	0	0	2
27	B2	Eastbound	Four barge	Ebb	4.0	1	1	0.0	0.00	0.0	0.0	2
28	B2	Westbound	Four barge	Ebb	4.0	1	1	1	1	1	1	6
					3.0	0	0	0	0	1	1	2
					2.0	0	1	0	0	0	0	1
29	B2	Eastbound	Four barge	Flood	4.0	1	1	1	1	1	1	6
					2.0	1	0	0	0	0	0	1
30	B2	Westbound	Four barge	Flood	4.0	1	1	1	1	1	1	6
					3.0	1	0	1	1	0	0	3
31	B3	Eastbound	Single barge	Ebb	6.0	1	1	0.0	0.00	0.0	0.0	2
32	B3	Westbound	Single barge	Ebb	6.0	1	1	1	1	3	3	10
					4.5	0	0	0	0	2	2	4
					3.0	0	0	0	0	1	1	2
33	B3	Eastbound	Single barge	Flood	6.0	1	1	1	1	2	2	8
34	B3	Westbound	Single barge	Flood	6.0	1	1	0.0	0.00	1	1	4
35	B3	Eastbound	Two barge	Ebb	4.0	1	1	0.0	0.00	0.0	0.0	2
36	B3	Westbound	Two barge	Ebb	4.0	1	1	1	1	1	1	6
37	B3	Eastbound	Two barge	Flood	4.0	1	1	0.0	0.00	1	1	4
38	B3	Westbound	Two barge	Flood	4.0	2	2	1	1	1	1	8
39	B3	Eastbound	Four barge	Ebb	4.0	1	1	0.0	0.00	0.0	0.0	2
40	B3	Westbound	Four barge	Ebb	4.0	1	1	1	1	1	1	6
					3.0	0	0	1	1	0	0	2
					2.0	0	1	0	0	0	0	1
41	B3	Eastbound	Four barge	Flood	4.0	1	1	0.0	0.00	1	1	4
					2.0	0	1			0	0	1
42	B3	Westbound	Four barge	Flood	4.0	1	1	1	1	1	1	6
												258

area, the eastbound runs began as though the tow was tied to the mooring wall in the east lock with a heading of 60 deg with no headway. The towboat captains increased speed to navigate past the bypass, clearing the Route 2031 bridge. The run was stopped approximately 1,000 ft past the bridge. The westbound runs began about 2,000 ft east of the bridge with a heading of 240 deg. The initial speed for this condition was 2.0 fps. The towboat captain drove through the bridge opening gaining speed to overcome the currents of the bypass channel and then reducing speed to stop in the east lock chamber.

Preconstruction and postconstruction river intersection experiments were run with the single-barge tow using velocity fields representing control velocities of 7.5 fps, 4.5 fps, 3.5 fps, 3.0 fps, and 1.5 fps. The two- and four-barge tows were run with control velocities of 2.5 fps and 2.0 fps. No current velocity above 2.5 fps (1.7 mph) was tested for these tows since tripping is required at 1.75 mph. The existing bypass channel area was run with all tows to establish a base condition with the present operating conditions. The three proposed bypass channels were run with two- and four-barge tows at control velocities of 4.0 fps, 3.0 fps, and 2.0 fps. The single-barge tow experiments were conducted using velocities of 6.0 fps, 4.5 fps, and 3.0 fps.

Experiment Procedures

Since the purpose of the study was to determine the operating limits of tows in the study area, the highest currents were run first. If failures occurred at the maximum velocities, they were decreased until the runs were successful.

Nine people from the Texas Waterways Operators (TWO's) association companies assisted in the study. These included three professional towboat captains who assisted during the validation, one of whom also performed experiment runs during the simulation testing. Two were active towboat captains and one was recently retired. Along with the validation pilots, five other towboat captains assisted in the real-time simulation experiment. One of the experiment pilots was recently retired from full-time piloting and is serving as a port captain now. Finally, one person served as a coordinator and observer arranging for these towboat captains to visit and work with WES. Seven companies participated in the experiment, including the following:

- a. Hollywood Marine, Inc.
- b. Stapp Towing Company, Inc.
- c. Coastal Towing, Inc.
- d. South Texas Towing, Inc.
- e. Dixie Carriers, Inc.

f. Sabine Towing and Transportation Co., Inc.

h. Higman Towing Company

Validation Experiments

To validate the simulation of the mouth of the Colorado River, towboat captains who regularly navigate through these locks visited the simulator prior to the actual experimenting. The purpose of the validation experiment was to verify and adjust, as necessary, model parameters such as tidal currents, bank effects, wind, towboat response, and objects in the visual scene based on the pilot's experience and familiarity with the study area.

During the validation effort, problems arose with the tow models. Due to the severity of these problems the validation period had to be extended. Changes made during the initial validation effort consisted of raising the eye level to give the towboat captain a more realistic view; determining an appropriate initial location; and adding telephone poles to the visual scene so that the captains could judge their speed more effectively.

When the revised towboat models were received from Tracor Hydraulics, sensitivity experiments were made to determine which coefficients had the most effect on lateral and longitudinal motion and the least effect on other parameters since these seemed to be the major concern. With some minor modifications to the rudder response and lateral motion, towboat models that were acceptable to the towboat captains were obtained. Final adjustments included adding two docks to the visual scene; making an aerial view available on a different computer that the towboat captains could not see so that an independent towboat captain could determine the success of the run; and making clearance information available to the captains. (Such information would often be provided to the tow captain by radio from a deckhand at the head of the tow.)

The maximum tidal fluctuations were estimated from available field data to be 4 fps. Steady-state runs were made for velocities of 3.0 fps, 2.0 fps, 1.0 fps, and 0.5 fps with an additional velocity of 4.0 fps in the bypass channel. Comparisons of measured to modeled velocities were made at a point in the bypass channel south of the GIWW and in the Colorado River upstream of the intersection. Additional flows of 2.5 fps and 5.0 fps were developed for the river intersection during validation by multiplying the 3.0 fps by constant values. The 2.5-fps current was needed because this is the current velocity at which tows are required to begin tripping across the river. Also, because the towboat operators anticipated higher flows in the river than 3.0 fps, an additional experiment condition of 5.0-fps velocity was agreed upon. Attempts were made to rerun the TABS-2 model at these flows, but time did not permit.

Since the longer tows (two- and four-barge tows) block a large portion of the channel when they are perpendicular to the flow, currents have a larger effect on these tows than on a small vessel. To account for this blockage effect, the currents were increased by 50 percent for the Colorado River and navigation bypass channel. The single-barge tow did not block the entire channel and did not require the effective increase in velocity used for the larger tows. This increase in effective currents for the large tows was found by the pilots to produce a satisfactory response in the simulation.

Experiment Results

River intersection

The preconstruction Colorado River intersection was tested as a basis of comparison with the new Colorado River diversion channel. The preconstruction river was used because the towboat captains had several years of experience navigating this condition and this experience was used in developing the model. In addition, this was the existing or base condition against which any changes in navigation conditions were to be measured. The experimenting began with the highest current velocity; for the single-barge tow this was 7.5 fps. As shown in Plate 1, none of the captains could make a successful run in the preconstruction river intersection with the single-barge tow transiting westbound with a 7.5-fps river current. In fact, none of the captains could make successful runs with this current magnitude either eastbound or westbound in the existing or diverted river channel. The captains said that this is an extreme condition that does occur occasionally and they normally are able to navigate it with one barge.

There are several possible reasons they experienced "failures" compared with normal "real life" successful transits at this condition. This condition was added subsequent to the validation at the insistence of the towboat captains. Due to time constraints, the current database for the 7.5-fps current was extrapolated from the 3.0-fps database by simply multiplying the velocity magnitudes by 2.5 instead of generating them with the numerical model as were the other currents. It is probable that a different current pattern would be developed for this much higher flow condition. Another possible reason these failures occurred is the operating procedures at these high current velocities. Exceeding the channel limits is common in such currents. In fact, if sufficient control is not maintained, the operators will actually "lay on" or touch the bank to reduce speed and reposition their tows to align with the lock. These procedures cannot be modeled well since the assumption is made that the towboat will remain inside the designated channel. If the tow leaves the channel, the current forces on the tow remain the same as the forces acting on the tow when it was last inside the channel. Therefore, if the captain left the channel to an area of slower current, which they do in "real life," the tow would be acted on by incorrect currents. In addition, the simulator does not

stop the tow as the tow would actually behave when it touches the bank or other fixed objects.

Of the six captains that conducted westbound runs of the preconstruction river channel with a 4.5-fps current, four were successful. Likewise, the same four were successful at the same current level with the new diversion channel with westbound transits. Two of the pilots were not successful at this current level and complained that the single-barge tow did not respond the way they had experienced a single-barge tow to handle in similar situation. However, three of the other captains indicated that this tow model was responding similar to what they expected. These two pilots continued to fail to make successful runs of the river for 3.5 fps and 3.0 fps and were finally successful with the 1.5-fps currents. Plate 2 shows the composite track-lines of these two captains' westbound runs through the river with the diversion channel and 3.5-fps velocities. This plate shows all runs illustrated by snapshots of the tow taken every 5 seconds, plotted one after the other. These seem to be unusually bad runs and these captains were having serious difficulty in controlling the single-barge tow, much different from the other four captains. These two pilots were not included in any other experiments of the single-barge tow in the river intersection, and results of their runs were not included in the analysis.

Single-barge tow. Results of westbound single-barge experiments of the river intersection, described as conditions 1 and 7 in Table 1, were plotted on a graph of percent of successful operators versus decreasing current velocity (Plate 3). The plots for preconstruction and postconstruction experiments overlay each other signifying that both conditions were similar in difficulty. In both the preconstruction and the postconstruction river intersection runs westbound with the single-barge tow, none of the four captains made successful runs at 7.5 fps. Subsequently, all four pilots made good runs at 4.5 fps. The current velocity at which 100 percent success was reached, 4.5 fps in this case, is called the threshold velocity. At current velocities at the threshold or below, safe operating conditions are anticipated.

For eastbound runs of the preconstruction river channel with a single-barge tow and 4.5-fps current magnitude, two of the four captains made successful runs. This condition is labeled condition 2 in Table 1. Of the other two, one succeeded at 3.5 fps and the other needed the current magnitude lowered to 3.0 fps. With the diversion, only one captain of the four was successful at 4.5 fps. This is shown as condition 8 in Table 1. Two additional captains were successful at 3.5 fps and the last made a good run at a current magnitude of 3.0 fps. A comparison of the preconstruction and postconstruction results are shown in Plate 4. The threshold velocity in both cases is 3.0 fps.

Two-barge tow. The highest effective current magnitude tested for the two-barge tow was 2.5 fps. The 2.5-fps current magnitude corresponds to 1.7 mph. This was used because it is just below the maximum velocity at which the towboat captains said that tows were allowed to cross the river without tripping, 1.75 mph.

For the westbound runs of the preconstruction river with the two-barge tow and 2.5-fps current velocity, all six towboat captains made successful runs (condition 3 in Table 1). A plot of the composite track-lines is shown in Plate 5. In the postconstruction river, five of the six towboat captains made successful runs with the two-barge tow transiting westbound across a 2.5-fps river current (condition 9 in Table 1). The sixth towboat captain made a successful run when the current velocity was decreased to 2.0 fps (1.4 mph). As seen in Plate 6, the threshold velocity for the postconstruction river plots below that of the preconstruction river. This indicates that the preconstruction river was less difficult than the postconstruction river in this condition.

On the other hand, Plate 7 shows that the preconstruction river was more difficult than the postconstruction river in the similar eastbound condition. These transits in the preconstruction river with the two-barge tow and 2.5-fps current velocity are listed as condition 4 in Table 1. Five of the six captains failed runs of this condition. Those five made successful runs with the 2.0-fps current velocity. Condition 10 in Table 1 has the river diversion implemented with the two-barge tow transiting eastbound in a 2.5-fps current. Three of the six towboat captains made successful runs of this condition. The other three captains were successful with the 2.0-fps current magnitude.

Four-barge tow. The four-barge tow runs westbound with the preconstruction river channel and 2.5-fps current velocity correspond to condition 5 in Table 1. Five of the six captains were successful in navigating this condition. The sixth was successful at 2.0 fps. The postconstruction river with the four-barge tow heading westbound is described as condition 11 in Table 1. With the current magnitude at 2.5 fps, three of the six pilots made successful runs. Two required the current to be reduced to 2.0 fps before succeeding and the last did not make runs at velocities less than 2.5 fps. These results are shown in Plate 8. It was assumed that the pilot who did not make a run of the 2.0-fps current would have been successful if he had. In this condition, the preconstruction river intersection was transited more successfully than the postconstruction intersection; however, they both have the same threshold velocity.

With the eastbound runs of the four-barge tow in the preconstruction Colorado River with a 2.5-fps current (condition 6, Table 1), four of the six captains made good runs. The other two made good runs when the current was decreased to 2.0 fps. In the postconstruction river with the four-barge tow and 2.5 fps (condition 12, Table 1), again two captains failed. However, these are not the same two that failed in the preconstruction river. The two did succeed at 2.0-fps current velocity. The graph of these two conditions is shown in Plate 9 and illustrates that these two were similar in difficulty.

Navigation bypass channel

As expected, the existing condition (no bypass channel) experiments were successful in all cases (Plate 10). This plate shows conditions 1- 6 in Table 2. At this time, there are no navigation problems entering or leaving the lock area, and it can be anticipated that the addition of crosscurrents in this area will decrease safety.

As seen in Plates 11, 12 and 13, the composite track-line plots of all tows in Plans 1, 2, and 3, respectively, show that all three bypass channels were acceptable for the eastbound ebb tide condition (conditions 7, 11, 15, 19, 23, 27, 31, 35, and 39 in Table 2). It should be noted that a wider swept path is a result of the introduction of crosscurrents in this area. This indicates reduced margins of safety and increased risk. These plots are for runs with the maximum current velocity tested for each tow, 6.0 fps for the single-barge tow and 4.0 fps for the two- and four-barge tows. All pilots were successful at this level of flow.

Single-barge tow. The track-lines of the westbound runs of the single-barge tow implementing Plan 1 with a 6.0-fps ebb tide are shown in Plate 14. This corresponds to condition 8 in Table 2. All four towboat captains failed at 6.0 fps. Captain A attributed this to, "Strong eddies around lock opening required high rate of speed to overcome effects of the outdraft through cut." Two succeeded at 4.5 fps and the two that failed at 4.5 fps were successful at 3.0 fps. However, with the Plan 2 condition, 20 in Table 2, five of the six captains who participated in experimenting were able to make this condition successfully with the 6.0-fps current. The Plan 3 case (condition 32, Table 2) was similar to the Plan 1 condition in that it took reducing the current to 3.0 fps for two of the captains to make successful runs. These two towboat captains said they thought that there was something wrong with the simulation for this condition because they felt they were being set north instead of south. The northerly set is apparently caused by the extreme changes in the bank effects in the Plan 3 condition. The single-barge tow is relatively short in relation to the length of the cut in the south bank, particularly when compared with the ones in Plans 1 and 2.

Plate 15 shows the graph of the percent successful pilots versus decreasing current velocity. This graph illustrates that two captains had more problem with Plan 3 than Plan 2. Plan 1 was the most difficult of the three. This plot also shows that the threshold velocity for Plan 2 was 4.5 fps and for Plan 1 and 3 it was 3.0 fps. This indicates that Plan 2 can be navigated safely at higher current magnitudes.

On the eastbound runs of the Plan 1 condition with a flood tide (condition 9 in Table 2), all four towboat captains made successful runs at 4.5 fps after failing at 6.0 fps. As seen in Plate 16, all four captains hit the north bridge fender at 6.0 fps. Even with the current lowered to 4.5 fps, two captains commented "very close" and "barely made this." With the Plan 2 condition, 21 in Table 2, all captains could make successful runs with the 6.0-fps flood

tide current. However, Captain C commented, "current caused bad set - could cause damage to bridge." It can be seen in Plate 17, despite the captain's evaluation that they were successful, at least two runs came very close to the north bridge fender. For the eastbound runs of the single-barge tow with a 6.0-fps flood tide implementing the Plan 3 bypass channel (condition 33 in Table 2), five of the six towboat captains were able to make successful runs of the maximum current magnitude. The one that failed did not rerun this condition. The plot of percent successful pilots for these conditions (Plate 18) shows that Plan 1 is the most difficult channel. The threshold velocity for the Plan 2 channel was 6.0 fps, whereas it was 4.5 fps for Plans 1 and 3.

For the westbound runs of the single-barge tow with flood tide, the Plan 1 condition (condition 10 in Table 2) required a 4.5-fps current magnitude before all captains could make successful runs. With Plan 2, all six of the captains made successful runs with the 6.0-fps flood tide. The track-line plot of this condition, 22 in Table 2, is shown in Plate 19. Of the four captains that attempted the Plan 3 condition with the 6.0-fps current, none failed (condition 34 in Table 2). A comparison of the three bypass channels is shown in Plate 20. Plan 1 is shown to be the most difficult. Plans 2 and 3 are similar in that they were successfully navigated by all pilots at the maximum current magnitude. Thus, their threshold velocity is 6.0 fps. For Plan 1, the threshold velocity is 4.5 fps.

Two-barge tows. The same pattern is shown in Plate 21. The conditions shown here are the two-barge tow westbound runs with an ebb tide, conditions 12, 24 and 36 in Table 2. The threshold velocity for Plans 2 and 3 is 4.0 fps, the maximum current velocity studied. For Plan 1, the threshold velocity is 3.0 fps. Three of four captains made successful runs with Plan 1 at 4.0-fps ebb tide. However, two captains who made acceptable runs said that they had too much speed entering the lock to stop "before getting too close to gate." The other captain was successful at a velocity of 3.0 fps. All six captains made successful runs of the Plan 2 condition with 4.0-fps current. Again two captains stated that at 150 and 200 ft, they came too close to the west gate. Westbound runs of the two-barge tow with the Plan 3 bypass channel and the current ebbing at 4.0 fps are shown in Plate 22. Again, all six towboat captains completed successful runs of this condition but, as seen in this plate, the tows were stopped very close to the gate.

For the two-barge tow eastbound with a 4.0-fps flood tide in the Plan 1 condition, two of the six captains failed to make a successful run, condition 13 in Table 2. These two evaluated their runs at 3.0 fps as successful. They then said, "This can be made with 1,000 hp. Any less wouldn't be able to." This seems to be an accurate statement since, as seen in Plate 23, they are out of the channel on both sides. For the Plan 2 condition with two barges heading east with a 4.0-fps flood tide, all four captains who tried made successful runs. This condition is denoted as 25 in Table 2. However, from looking at Plate 24, it is too close to the north bridge fender, as well as the south lock guide wall, to

be considered safe. Similarly, all four captains succeeded in the Plan 3 channel. The eastbound two-barge runs of this plan are referred to as condition 37 in Table 2. Considering the pilots' evaluation of these runs to be correct, the plot of these results, Plate 25, shows that Plan 2 and 3 were both successfully transitted at the maximum velocity, 4.0 fps, while Plan 1 had a threshold velocity of 3.0 fps.

The two captains who ran the westbound two-barge tow in Plan 1, condition 14 in Table 2, with a 3.0-fps flood tide made successful runs after failing at 4.0 fps. Since Plan 1 was consistently worse than Plans 2 and 3, it was agreed with District personnel that the study should focus primarily on Plans 2 and 3. When it became apparent that time would not allow experiments with all conditions, the Plan 1 condition was not tested. This is why only two operators made runs of Plan 1. One captain stated that even the 3.0-fps current velocity "could cause problems if tow does not have good backing power," indicating he was concerned about a high tow speed approaching the lock gate. With the Plan 2 scenario, the same two captains failed at 4.0 fps; however, the other four made successful runs. These two made good runs at 3.0 fps in this condition, 26 in Table 2. In the Plan 3 scenario of this condition, 38 in Table 2, five of the six towboat captains made successful runs of the westbound two-barge tow with a 4.0-fps flood tide. Captain A said he was, "extremely close to the bridge fender wall" and Captain C complained of "problems getting into locks." For this condition, the plot of percent successful, Plate 26, shows that Plan 2 is more difficult than Plan 3. However, all plans have the same threshold velocity, 3.0 fps.

Four-barge tows. With the four-barge tow, westbound run of the Plan 1 condition with an ebb tide, referred to as condition 16 in Table 2, only one of the three captains was able to make a good run with the 4.0-fps current magnitude. One captain made a successful run at 3.0 fps, and the last required a 2.0-fps current to make an acceptable run of this condition. Plate 27 shows the westbound four-barge tow with the Plan 2 scenario in a 4.0-fps ebb tide, condition 28 in Table 2. Three of the six captains made successful runs of this condition. As the plot shows, the pilots navigated through the bridge successfully but drifted too far south to recover in time to make the lock. Two of the three who failed at 4.0 fps made good runs with 3.0-fps current. The third accidentally tested 2.0 fps and not 3.0 fps, which he navigated successfully. It is thought that, since the other two captains made successful runs, the 3.0-fps current magnitude would have been also successfully navigated by this captain. Similarly, with Plan 3, three of the six succeeded, condition 40 in Table 2. Two were successful at 3.0 fps and one at 2.0 fps, not having tested 3.0 fps. Based on the pilots' evaluation, the plot of percent success versus current velocity (Plate 28) shows the same level of difficulty for Plans 2 and 3. Plans 2 and 3 show a threshold velocity of 3.0 fps while Plan 1 had a threshold of 2.0 fps. However, for this condition with a 3.0-fps ebb tide, the tow track plots for Plan 3 look significantly better than for Plan 2, as shown in Plates 29 and 30.

For the four-barge tow navigating east in the Plan 1 condition with a 3.0-fps flood tide, condition 17 in Table 2, four of the six captains failed this condition with the 4.0-fps current. These four made successful runs at 3.0 fps. The towboat captains expressed concern with "breaking the tow in half." It seems that the rudder required to control the tow could cause the lines holding the tow together to break. With the Plan 2 condition, 29 in Table 2, five of the six captains made successful runs. The one who did not was accidentally given 2.0 fps as the next velocity, and he made a good run at this velocity. The same situation happened to a different captain for the Plan 3 run of this condition, 41 in Table 2. He did not make the run at 4.0 fps and was given 2.0 fps as the next current magnitude instead of 3.0 fps. The other three towboat captains made successful runs of the 4.0-fps velocity. In both cases, it was felt that these captains could have made successful runs at 3.0 fps if they had tested that condition. The graph of the percent success versus current velocity is shown in Plate 31. Plan 1 is shown to be the most difficult bypass channel and Plan 2 the least difficult. This is consistent with the track-lines shown in Plates 32 and 33. The Plan 2 condition looks slightly better than Plan 3 at 2.0-fps current velocity.

Four captains used the four-barge tow westbound in the Plan 1 condition with a 4.0-fps flood tide, condition 18 in Table 2. Plate 34 illustrates the extreme difficulty of this run. Of these four captains, only one was able to make a successful run. Five captains tried the 3.0-fps current; three succeeded. The last two required a current of 2.0 fps before successfully completing a run. The four-barge tow heading west crossing the Plan 2 bypass with a 4.0-fps flood tide is shown as condition 30 in Table 2. Five of the captains were able to navigate this condition successfully. One of the pilots who made a successful run said, "With any less horsepower than 1,800 there would be no way that this tow could be handled in this type of current." The last succeeded at 3.0 fps. Condition 42 in Table 2 involved the Plan 3 scenario with a westbound four-barge tow crossing a flood tide at 4.0 fps. All the captains were judged to be able to successfully navigate this condition; their track-lines are shown in Plate 35. From this plate it looks as though the lock wall was hit in one run, but it can be seen from Plate 36 that the tow was safely within the lock gate. This was considered a good run since in reality the wall would have held the tow off. The plot of percent success (Plate 37) shows that Plan 1 had a threshold velocity of 2.0 fps, Plan 2 required that the current be reduced to 3.0 fps, and Plan 3 had successful runs by all pilots at the highest current magnitude, 4.0 fps.

Conclusions

River intersection

The behavior of a single-barge tow in high currents was not modeled entirely successfully. Several factors were involved: (a) the currents were not modeled hydrodynamically for the high-current condition, i.e., computed

TABS-2 currents for a lower velocity condition were extrapolated to the high-velocity condition; (b) the tows were maneuvered outside the design channel into deep areas in the intersection where the currents were not defined, and therefore, the currents were not representative of that particular location; and (c) no fendering structures or soft banks were explicitly modeled to provide resistance against which the tow could be worked and maneuvered as captains normally do during standard operations. However, the single-barge tow did show an acceptable level of accuracy to use the results as a comparison of conditions before and after construction of the diversion channel and blockage of the existing river channel.

Plate 38 shows a bar graph of the threshold velocities of the river intersection runs. The overall threshold velocity identifies the maximum current considered to be safe for that tow. This is obtained by taking the minimum of the east and west transit threshold values, i.e., the velocity at which all captains using a particular condition were evaluated as having made a successful run. As seen in this plate, the overall current thresholds show no change from preconstruction to postconstruction conditions.

Plate 39 shows the captains' average ratings for the before- and after-construction conditions for four questions: difficulty of run, effect of current on the tow, amount of attention required, and danger of grounding or hitting an object. The larger the rating, the more dangerous the condition as perceived by the pilot. This plate shows that the captains rated the postconstruction river only slightly higher than the preconstruction river. Therefore, it is concluded that the implementation of the diversion channel as addressed in the GDM¹ will not hinder navigation at least for flows where the tow can remain in the navigation channel.

Navigation bypass channel

The navigation bypass channel will most definitely adversely impact navigation in the GIWW. The captains have demonstrated that they can easily navigate the existing channel from the Route 2031 bridge to the west lock with no problems. However, it is apparent from the many accidents during simulation experimenting with the bypass channel that this transit will be much more difficult when currents are introduced. This can also be seen from the difference in the captains' evaluation ratings between the existing and planned conditions in Plate 40.

As shown in Plate 41, the threshold velocity for the four-barge tow for the Plan 1 channel is 2.0 fps. These tows can be broken down to two- and single-barge tows at velocities up to 3.0 fps. However, velocities exceeding 3.0 fps will require a complete shutdown of operations. Based on analysis using steady-state currents, the Plan 2 bypass channel will require tripping tows at 3.0 fps and shutdown at 4.5 fps, as shown in Plate 42. Plate 43 shows that all

¹ U.S. Army Engineer District, Galveston, 1981, op. cit.

tow configurations can navigate the Plan 3 channel at velocities up to 3.0 fps. Above 3.0 fps, operations must cease.

The unpredictability of Plan 3 can be seen from this plate. For the westbound ebb condition, the two-barge tow can navigate at higher current velocities than the single-barge tow. This might have been explained by eliminating two captains who had problems with this condition; however, the westbound flood condition shows a similar pattern in that the four-barge can navigate at higher velocities than the two-barge. This phenomenon may be explained by the effect of the long opening on the south side of the channel, which causes a larger unbalanced bank force for the smaller tows. These unexpected results lead to the conclusion that the Plan 3 bypass channel should be avoided even though it was shown in most cases to be close to Plan 2 in difficulty.

4 Hydrodynamic Current Experiments

Steady-State Comparison

In order to expedite the study, the tow simulation experiments were run with steady-state currents. The steady-state currents were computed numerically with a TABS-2 hydrodynamic model¹ to provide a two-dimensional depth-averaged current pattern at various levels of flow that might be expected to occur during a tidal cycle. In order to determine the frequency and duration of various levels of flow that can be expected throughout a typical period of tidal cycles at the project's navigation bypass channel intersection with the GIWW, a more extensive dynamic TABS-2 model was developed and computations for a month of tidal cycles were executed concurrently with the navigation experiments. This was necessary because of the short time frame available for the study. The strategy of this approach was to determine the flow levels that created navigation difficulties for each of the typical tow sizes and transit situations that were likely to occur, i.e., threshold velocities. Then the period of time that such flows occurred over a typical month and the percent of time the tow traffic would be negatively impacted by the project, if any, would be determined from the dynamic tidal computations.

The results of the steady-state tow simulations were presented during a meeting on 29 August 1990 and described in a preliminary findings report.² An optimum bypass channel alignment, referred to as Plan 2, was recommended. Subsequently, the recommended plan was changed. These changes included a realignment of the navigation bypass channel and an increase in depth from the original uniform bottom elevation of -12 ft in the navigation study to -14 and -24 ft referred to the National Geodetic Vertical Datum (NGVD). The modified plan, referred to herein as Plan 2A, was used

¹ Hauck 1992, op. cit.

² Memorandum, CEWES-HR-N, 12 Dec 90, for Mr. Ed Reindl, U.S. Army Engineer District, Galveston, Subject: Mouth of the Colorado River, Texas, Navigation Impacts from Diversion into Matagorda Bay.

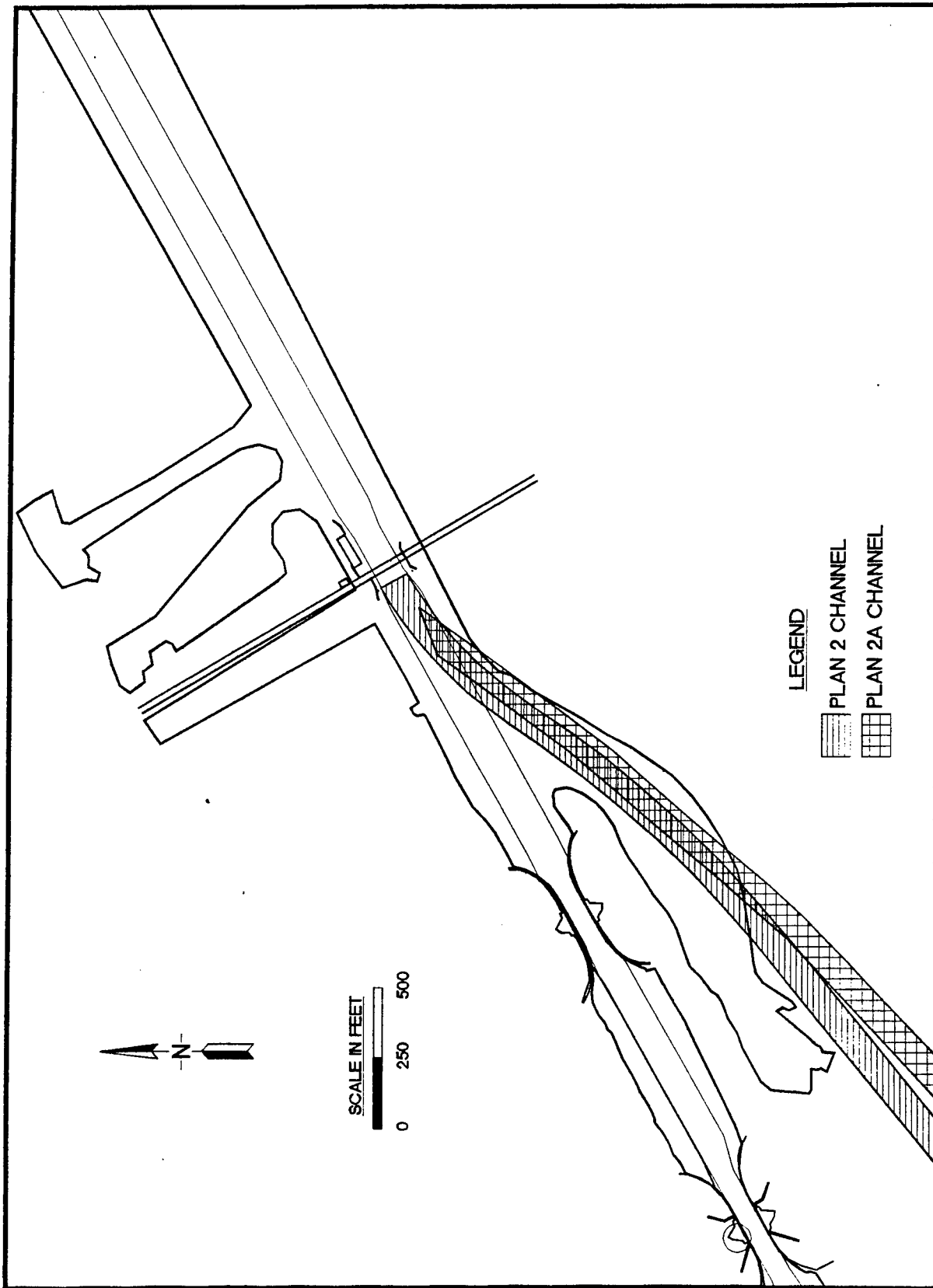


Figure 12. Plan 2 versus Plan 2A

in the dynamic tidal hydrodynamic runs. Figure 12 illustrates the difference in the alignment of the two plans.

Plate 44 shows the steady-state currents of Plan 2 tested in the navigation study for the ebb tide at a velocity of 2.0 fps. The dynamic tidal currents are shown in Plate 45 for the -24-ft depth, referred to as Plan 2A. These two illustrations show very similar velocity vectors. There is a shift in the location of the maximum currents of 50 ft as expected from shifting the bypass channel to the east. Plates 46 and 47 show the steady-state and dynamic currents, respectively, for the 2.0-fps flood tide. These two velocity vector plots are highly dissimilar. This can be seen more dramatically in Plate 48. The reasons for these differences were scrutinized. Four possible reasons were considered: (a) the change in the depth of the bypass channel, (b) the difference in steady-state versus tidally driven currents, (c) the realignment and relocation of the bypass channel, or (d) changes to the numerical grid made subsequent to running the steady-state runs.

The component of the current vector perpendicular to the GIWW along the center of the channel was used to evaluate what caused changes in the current conditions and the potential impact of the plans on navigation. The cross-currents were used since they are the main source of adverse navigating conditions. Figure 13 defines the graphical display of crosscurrent component variation along the channel center line presented in Plates 49-53.

Plate 49 shows the crosscurrent plots of the steady-state and the dynamic currents for the 2.0-fps ebb tide shown in Plates 44 and 45. As previously determined, the ebb tide conditions are similar except for the 50-ft shift in the bypass channel.

The flood tide plots of the crosscurrent (Plate 50) show that not only are the peak crosscurrents relocated but the dynamic crosscurrent velocity components are approximately 50 percent larger than in the steady-state case. These are the currents presented in Plates 46 and 47. If the 14.0-ft-deep channel is compared to the 24-ft-deep channel (Plate 51), very little difference is observed. From this it can be concluded that the change from a 12-ft depth in the steady-state condition to the 14- or 24-ft depth in the dynamic runs probably made an insignificant difference.

In order to distinguish changes resulting from the steady-state versus dynamic conditions, it was necessary to examine the differences between steady-state currents and dynamic velocity fields without changes in channel alignment. The most similar runs made between the steady-state and dynamic currents were those of the Plan 3 condition. The only difference between the Plan 3 conditions in the hydrodynamic models of the steady-state to the dynamic conditions was the depth. The steady-state model was run at a depth of 12 ft as opposed to the dynamic runs, which were made with a channel depth of 14 ft. As seen in Plate 52, the 2.0-fps flood tide plots of these two conditions are similar in magnitude with the peak magnitude of the dynamic crosscurrent occurring over a longer distance than the steady-state velocities.

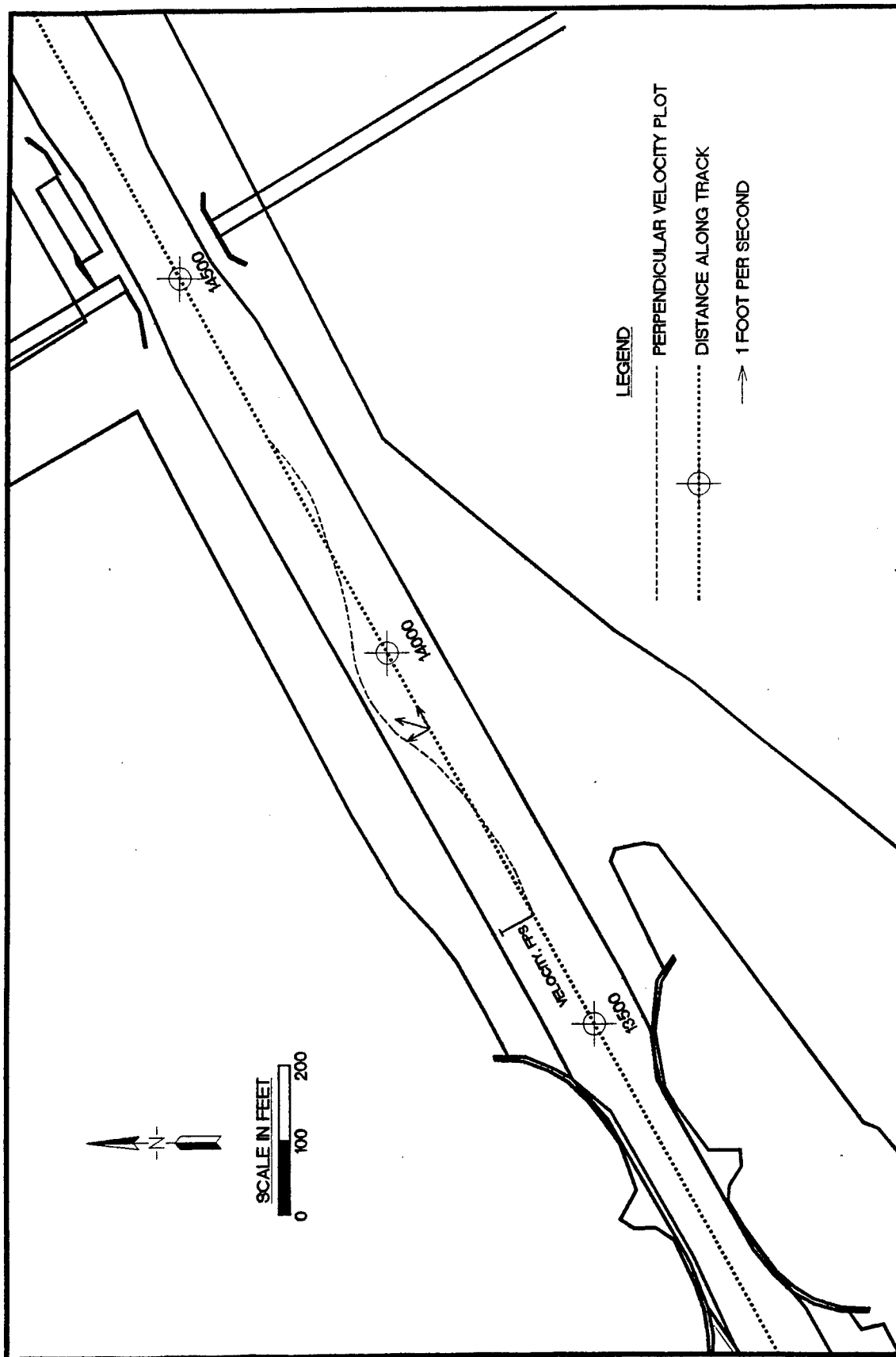


Figure 13. Illustration of perpendicular velocity plot

Since the conclusion has already been made that the depth does not have a significant impact on crosscurrent, it can be determined from this case that while the dynamic condition versus the steady-state condition causes some differences in the crosscurrent pattern, it does not account for the 50 percent increase in peak crosscurrent magnitude seen in Plate 50.

To determine the effect of the realignment and relocation of the bypass channel, tidal currents were run with the original Plan 2 design. As shown in Plate 53, little difference can be attributed to realigning the channel. Therefore, the differences in the crosscurrent pattern between the steady-state crosscurrents and the dynamic ones were created by the grid improvements. This was verified by running steady-state currents with the new grid and obtaining results similar to the dynamic runs.

Since the dynamic currents were felt to better reproduce the prototype, it was necessary to determine their effect on navigation. This question was addressed with autopiloted runs. The autopilot is designed to keep the tow on a given line. The line was defined to reproduce as closely as possible the tracks of the successful pilot runs. The successful pilot runs for the westbound flood tide condition are shown in Plate 54. Plate 55 shows the autopiloted runs for all tow sizes with the plan recommended in the navigation study (Plan 2) heading westbound with a 2.0-fps flood tide. The majority of the tracks stay within the channel limits with some minor excursions outside of the channel limits at the intersection of the bypass channel. The autopilot runs do not stop in the lock gate area with the same control as the man-piloted runs due to limited control in stopping and maneuvering within a small area. If this is compared with Plate 56, the effect on navigation of the dynamic currents can be seen. The tracks show that the barges have difficulty lining up to enter the lock gate. The navigation difficulties appear to exceed even those of the transits during the 3.0-fps steady-state current experiments as shown in Plate 57.

The safest way to estimate the threshold velocity was to have no perpendicular currents closer to the lock than in the experiment runs. As shown in Plate 58, the maximum velocity that meets this criterion is for the currents at hour 437. This is associated with a current of 1.4 fps. This is the new threshold velocity for the two- and four-barge tow. The threshold velocity for the single-barge tow will be decreased to 3.0 fps. This is shown in Plate 59, the revised Plan 2 threshold velocity plot.

Conclusions

Plan 1 had the lowest threshold velocities of the three plans experimented. It was so difficult to navigate that during experimenting it was given a low priority and some runs were not made. Because of this, no dynamic current modeling was done of Plan 1. Therefore, the actual threshold velocities cannot be ascertained.

Plan 3 illustrated threshold velocities of 3.0 fps for all tows. Plate 60¹ shows that the current does not exceed 2.0 fps for either flood or ebb tide. However, because of the extreme bank effects created by this bypass cut, it cannot be recommended.

Plan 2 had similar threshold velocities to Plan 3. However, these velocities were decreased because of the outcome of the dynamic modeling, as discussed in the last paragraph in the previous section. It is still believed that this bypass channel is better than Plan 3 since it showed no signs of adverse bank effects. In addition, three of the six captains recommended Plan 2 and one suggested either Plan 2 or 3 stating that both have good and bad points.

Plate 61 shows the tidal cycle and the corresponding threshold velocities. The ebb current will not create any delays from astronomical tide conditions propagating in the bypass channel. However, intermittent, multihourly delays may be expected during approximately ten cold front passages in early winter (Plate 62).

Because of the differences between the dynamic and steady-state current patterns during the flood tide, delays due to tripping are estimated to be as much as 15 percent of a 28-day period (Plate 61) due to additional crosscurrents near the lock gate. Time delays may be negligible if pilots are able to compensate for this difference. This can be verified by "check simulations" with pilots as proposed by WES.²

All findings are based on the west gate of the east lock chamber being closed. Otherwise, large northerly crosscurrents may develop and seriously impede navigation.

¹ Hauck, 1992, op. cit.

² Memorandum for Commander, U.S. Army Engineer District, Galveston, ATTN: Mr. Reindl, 23 April 1990, CEWES-HR-N, subject: Mouth of Colorado River, Navigation Impacts from Diversion into Matagorda Bay.

5 Recommendations

It is recommended that Plan 2 be used for the bypass channel. Plate 63 shows all successful runs of the Plan 2 condition. This plate demonstrates that the captains do exceed the channel limits. Even this bypass channel design will create a difficult navigation condition. Therefore, it is also recommended that further study be conducted to design a fender system for the area between the lock and the Route 2031 bridge at the junction of the bypass channel. A simulation guide wall study was initiated but did not provide the required information. A physical model study would be the best way to ascertain detailed design information. Completion of the bypass channel project should be temporarily delayed while the guide wall design is being developed.

Monitoring velocity gauges should be installed in both the Colorado River upstream of the GIWW intersection and the bypass channel. This will allow lock personnel to advise tow captains of adverse flow conditions.

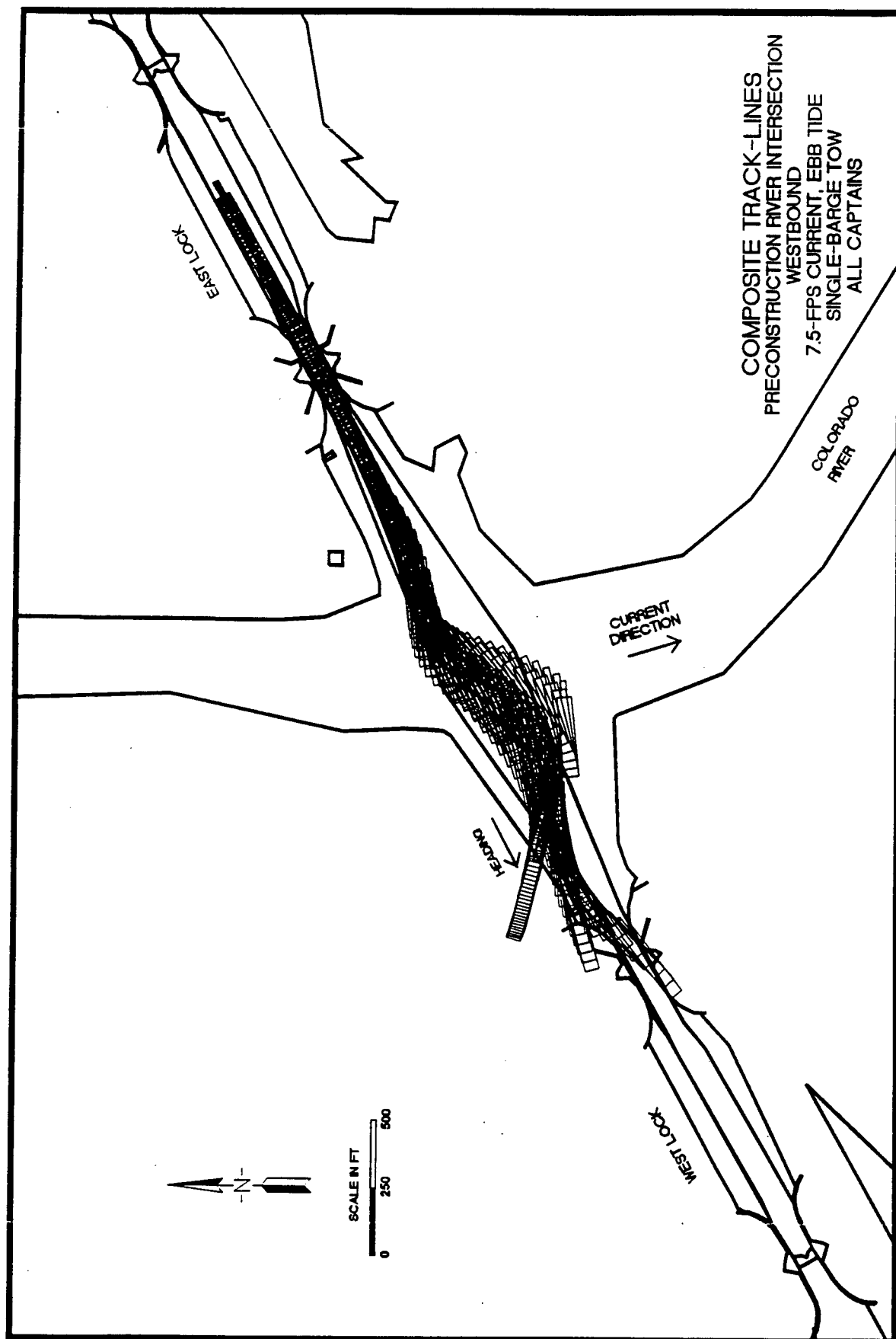


Plate 1

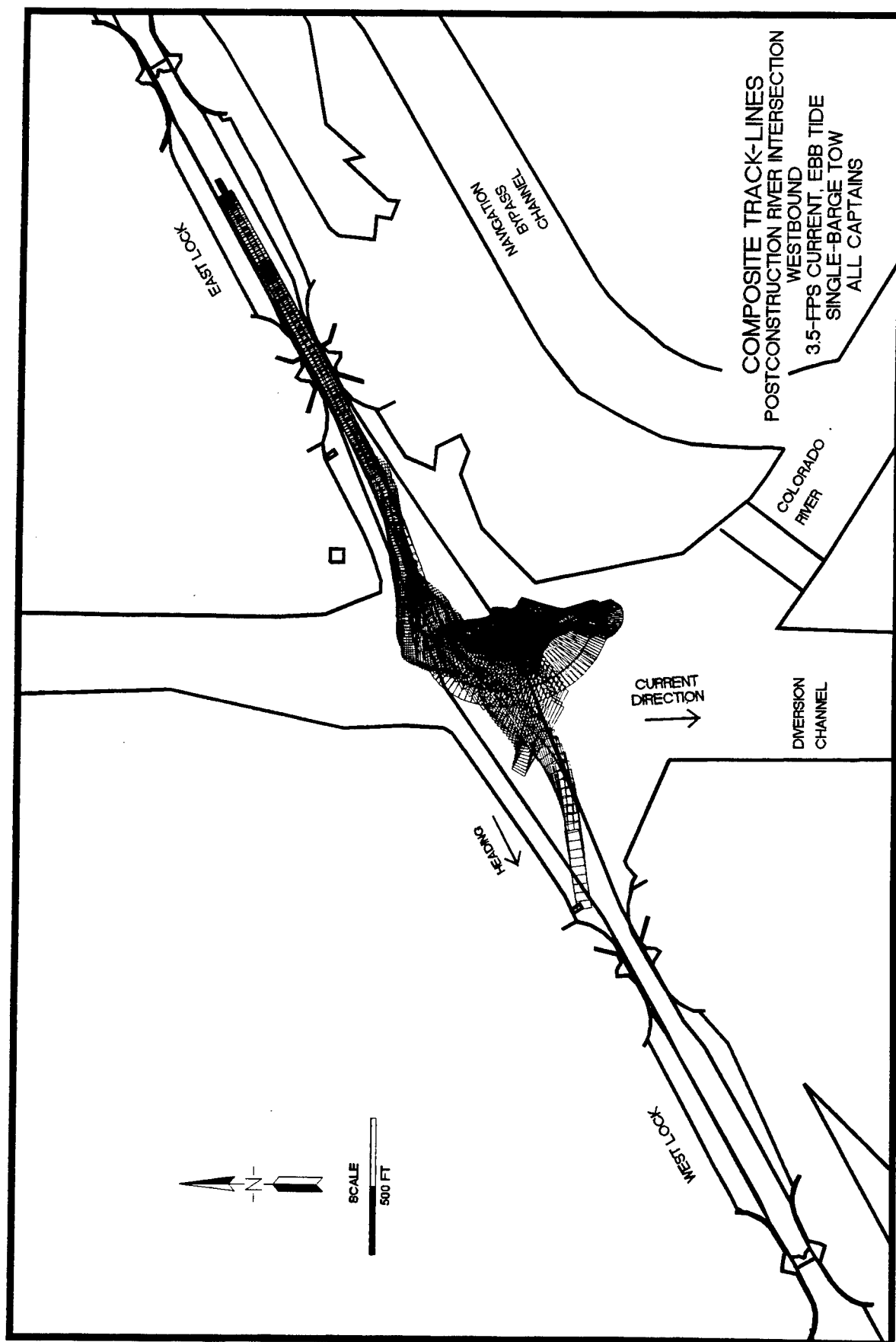
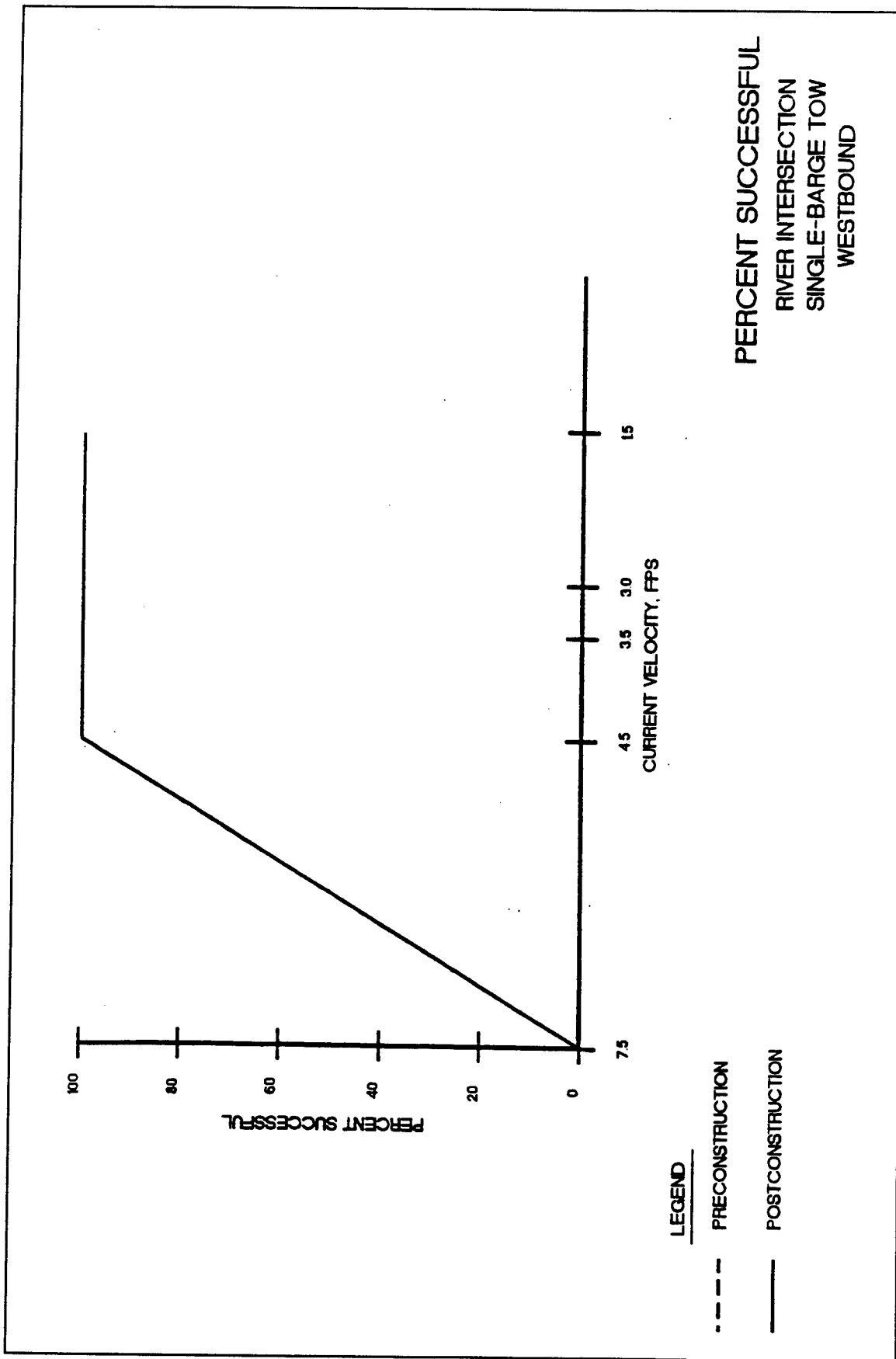


Plate 2



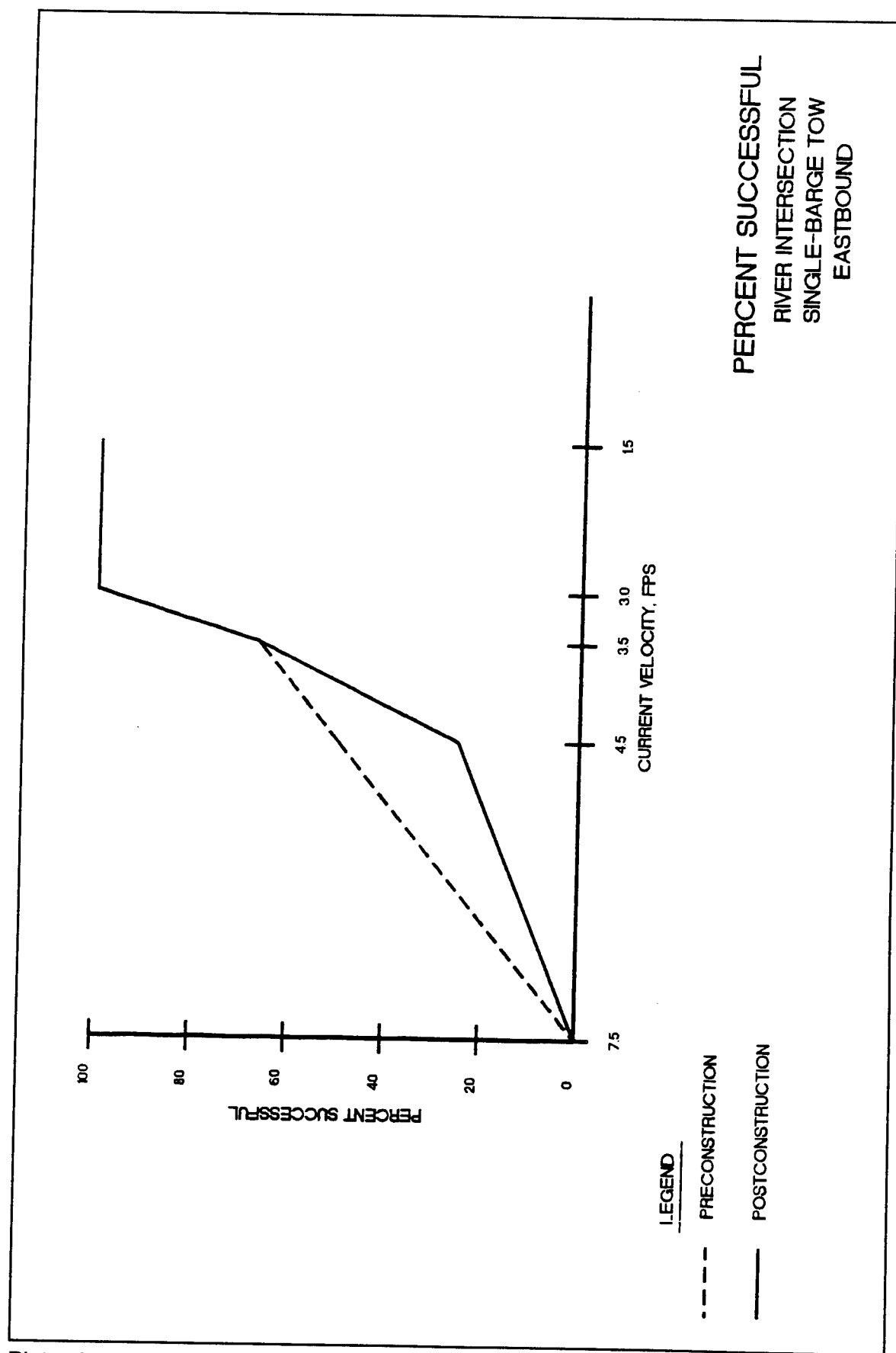


Plate 4

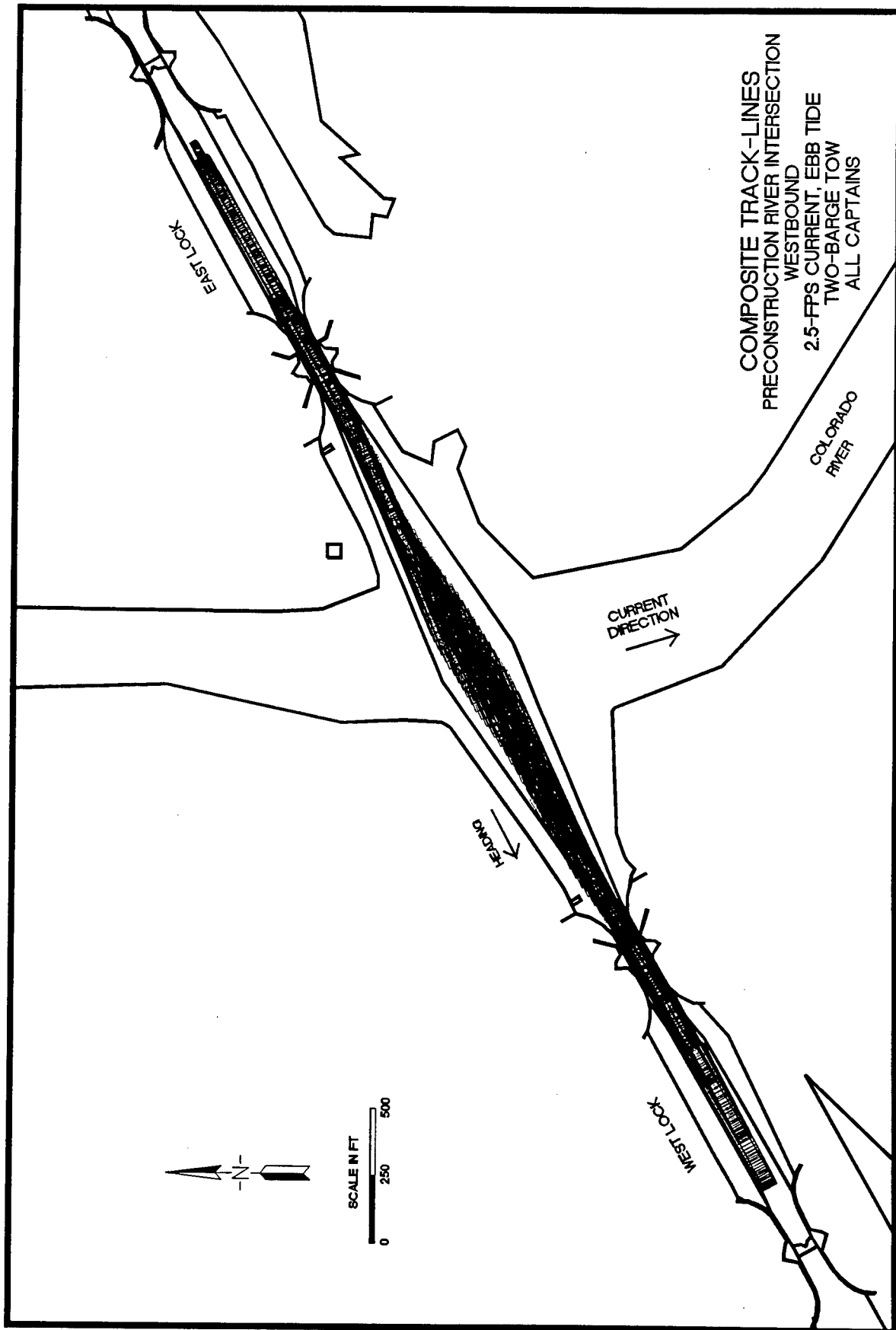


Plate 5

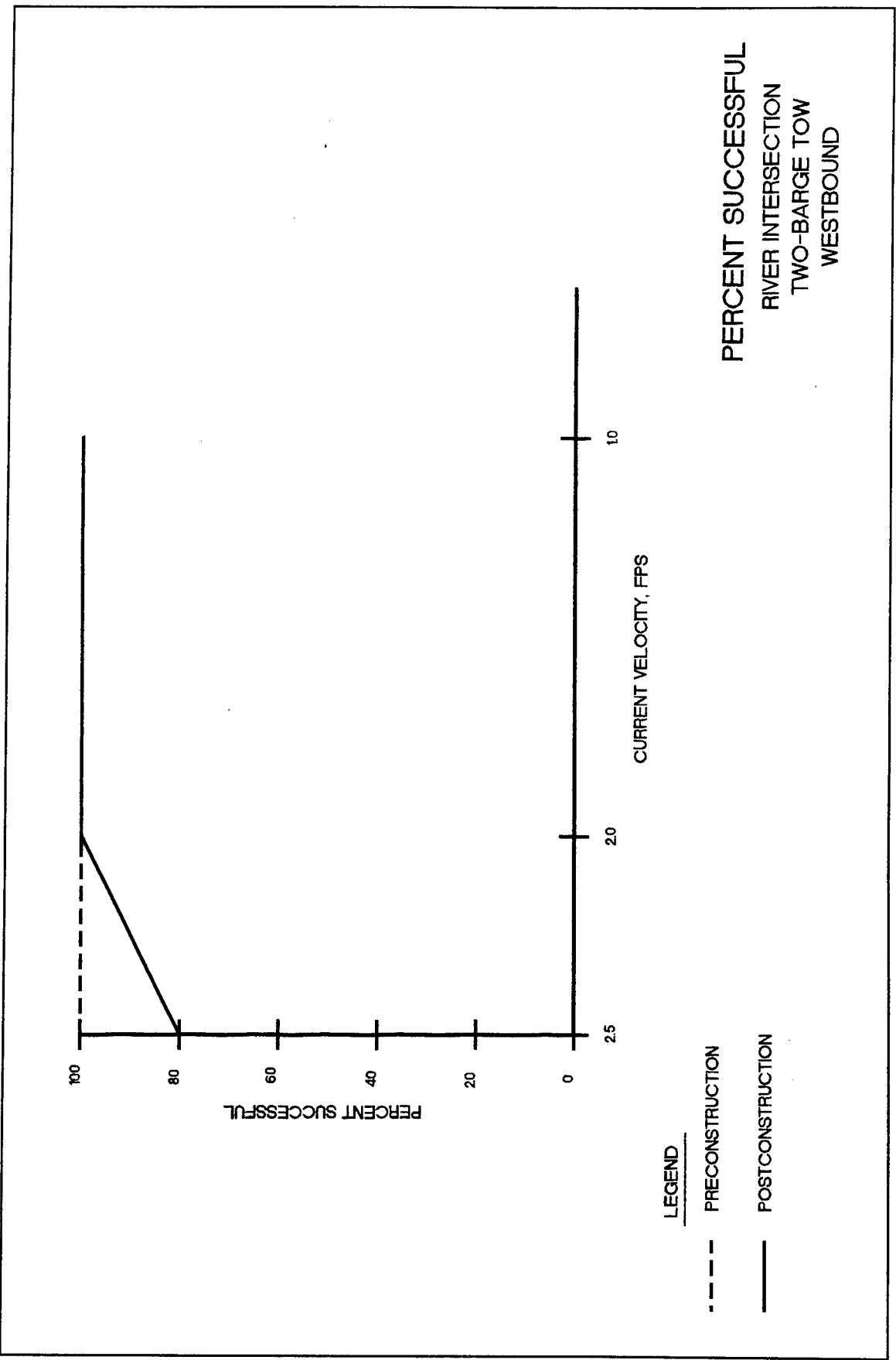
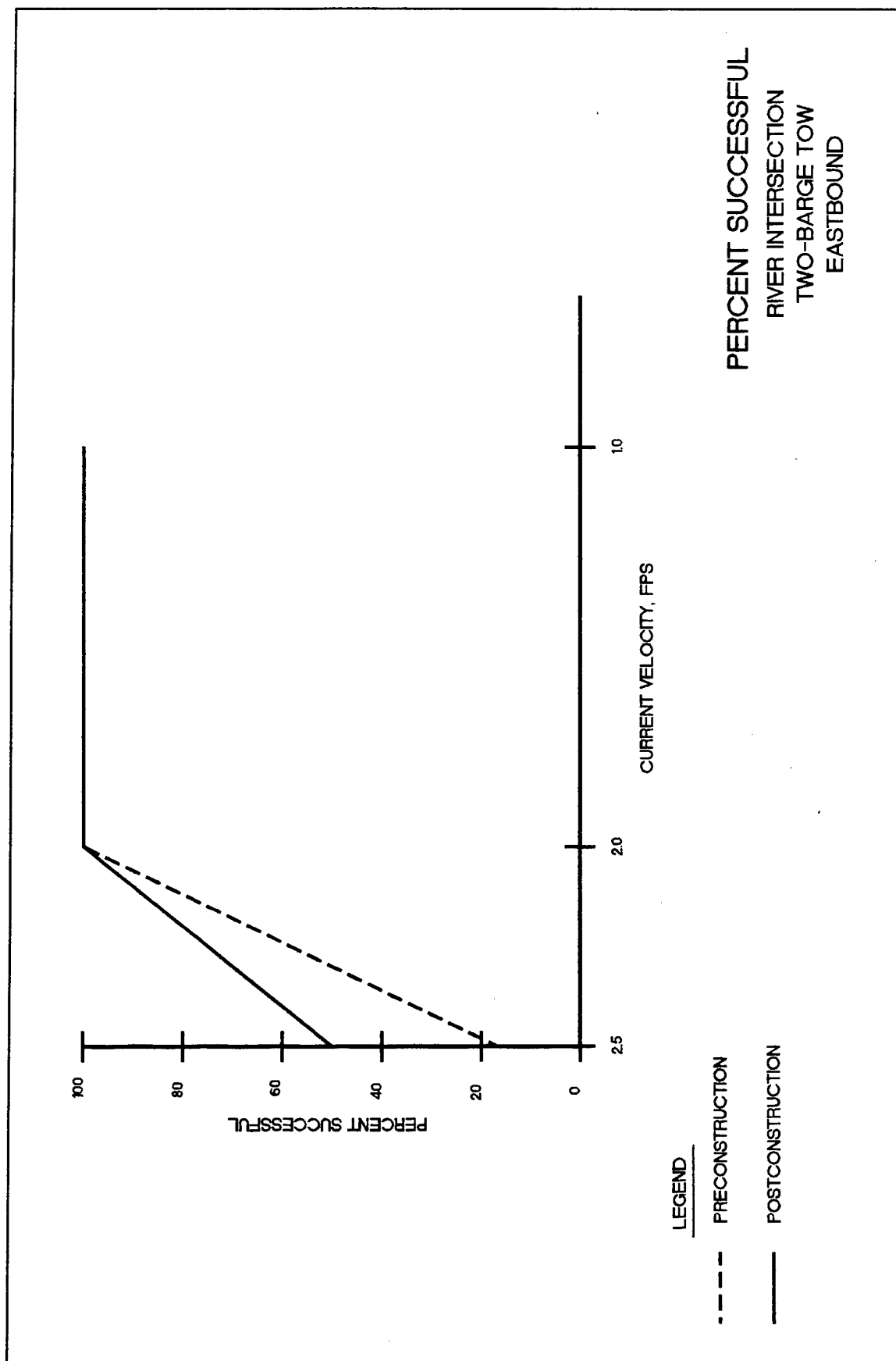


Plate 6



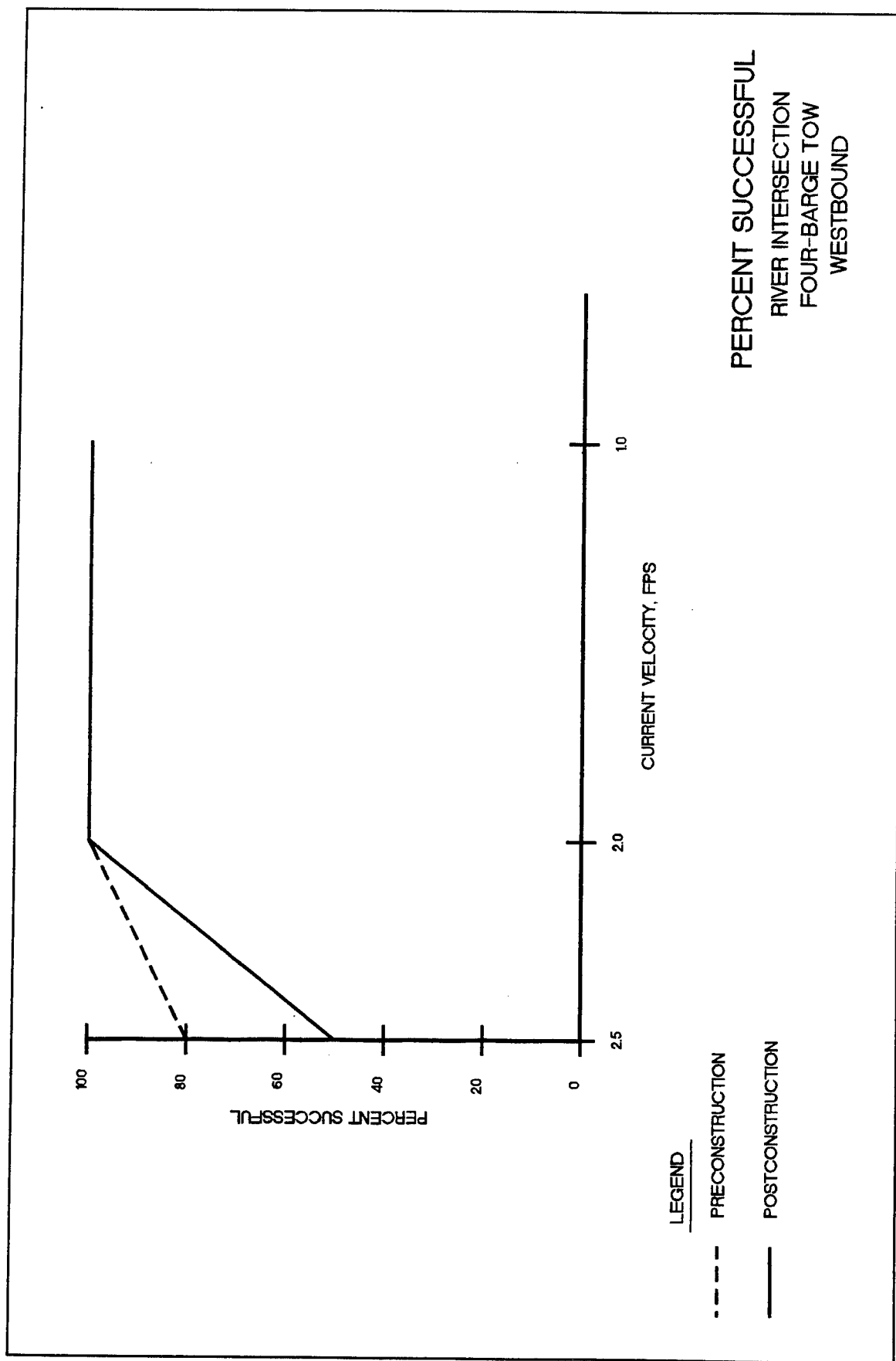


Plate 8

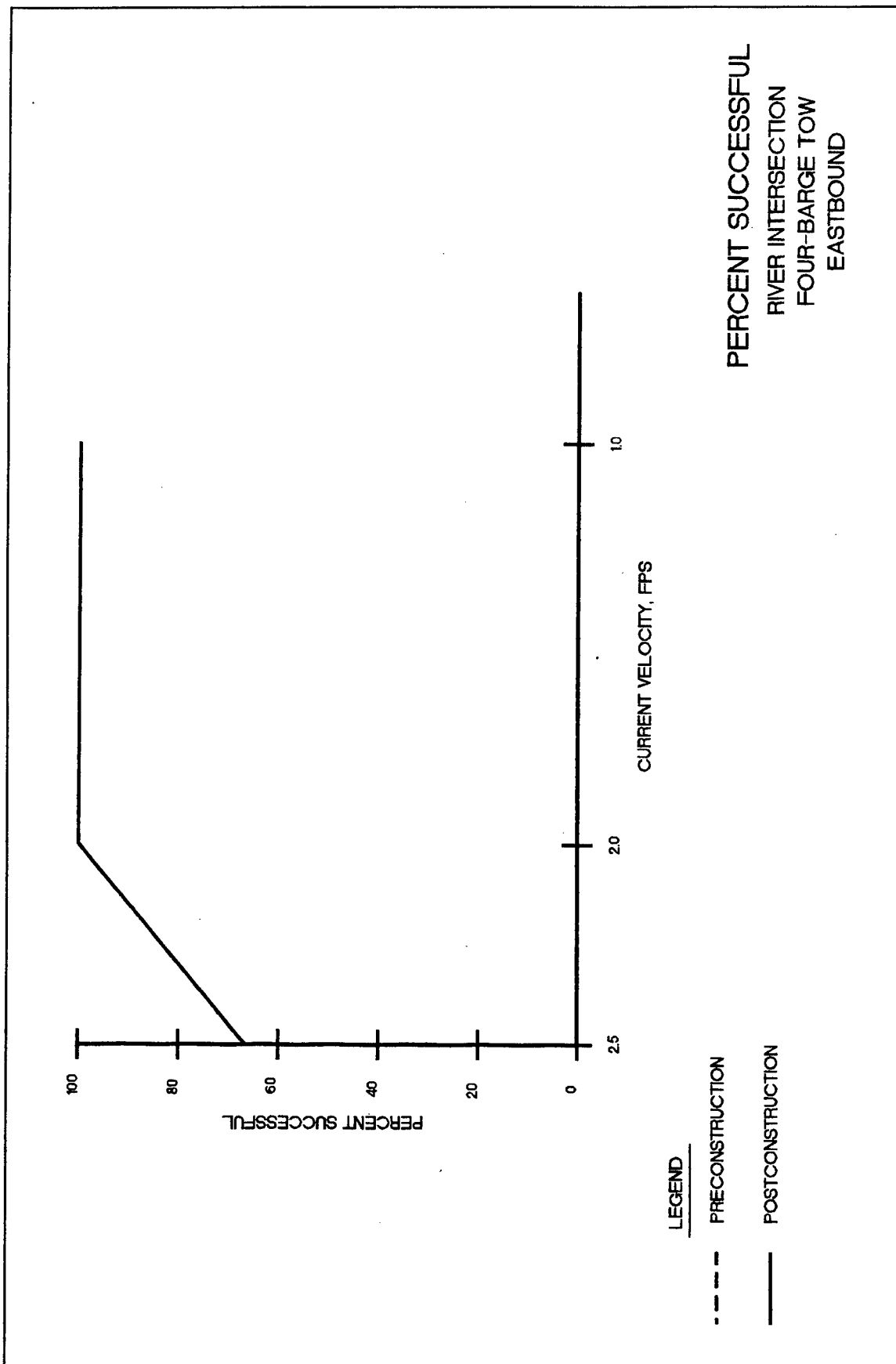


Plate 9

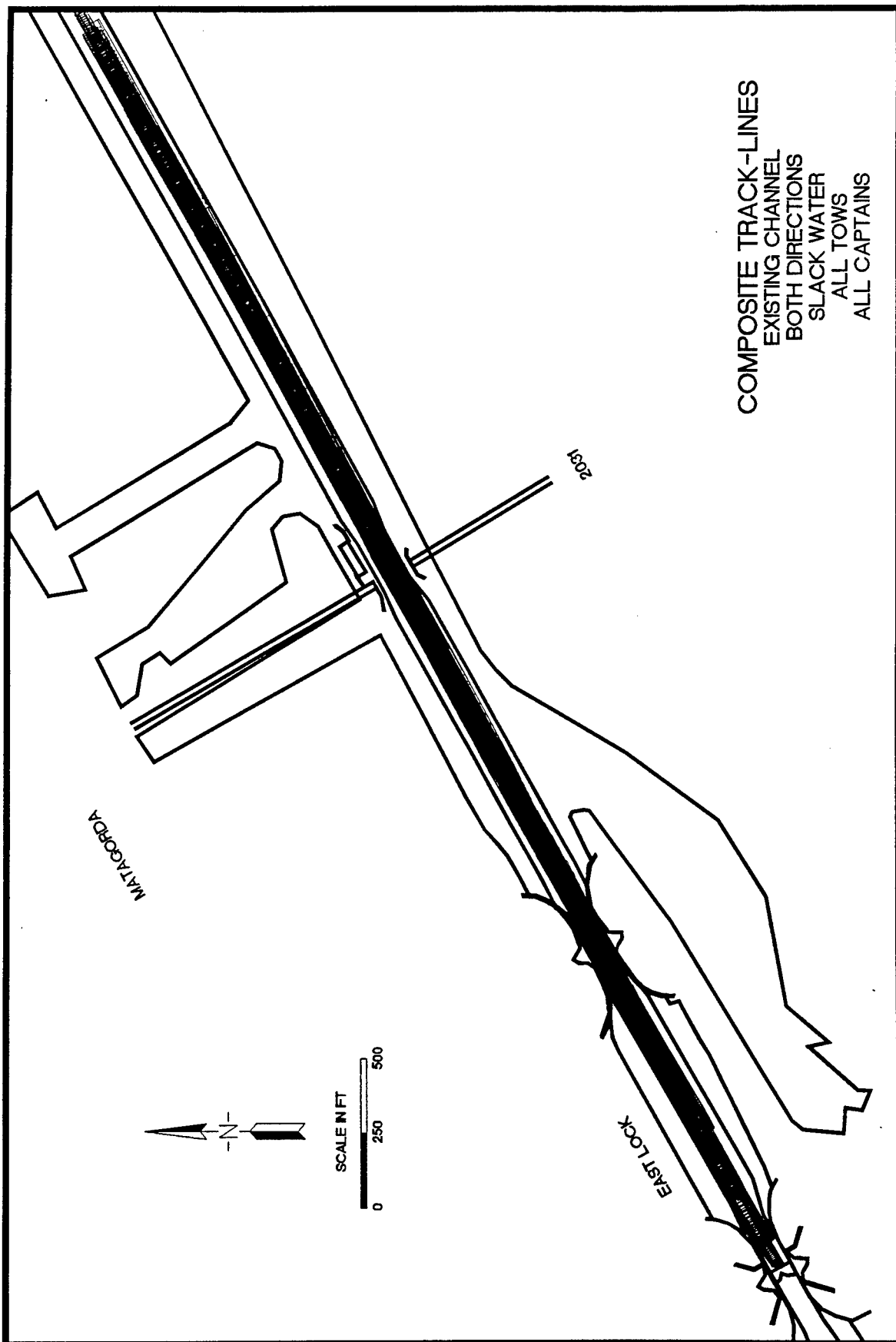


Plate 10

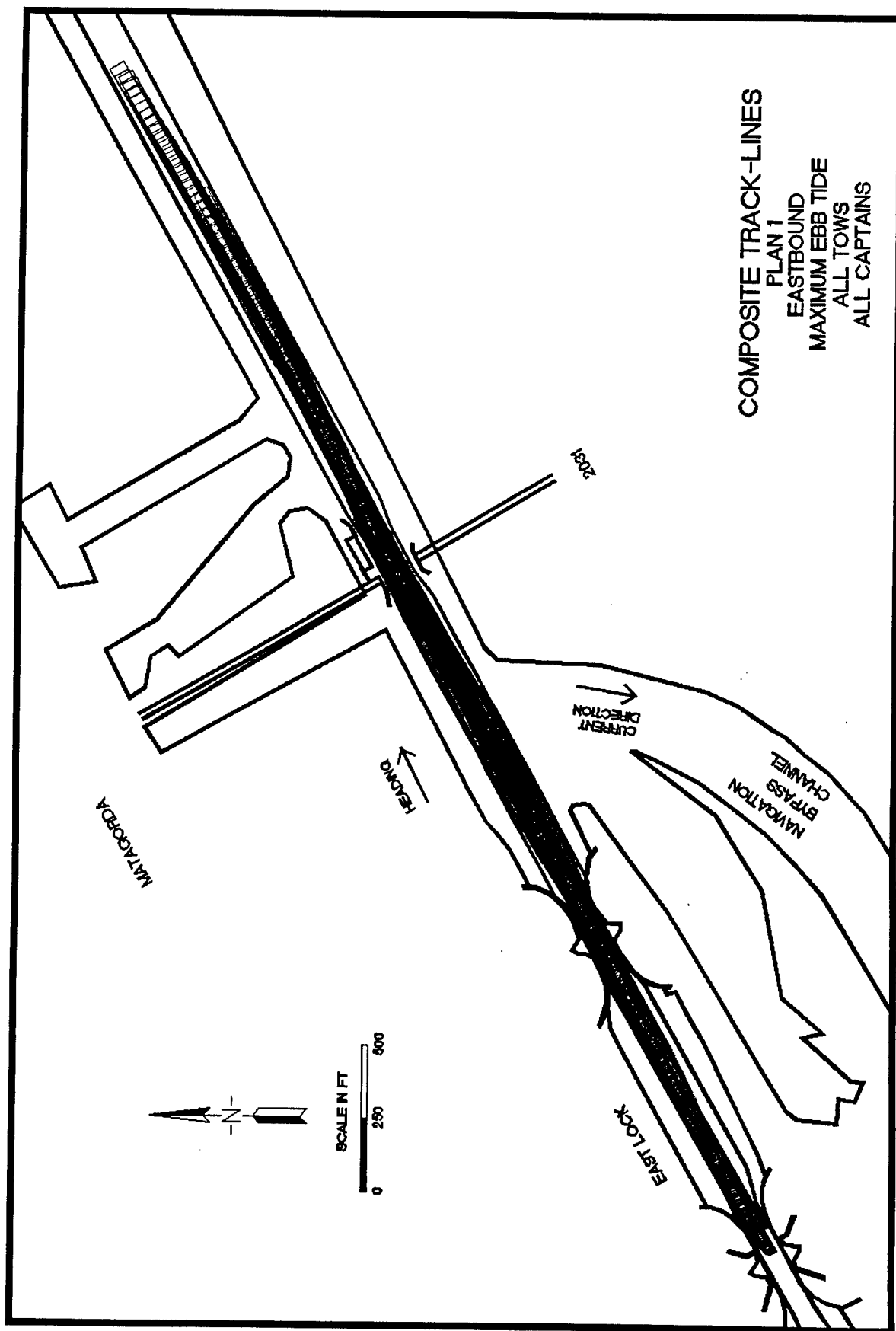


Plate 11

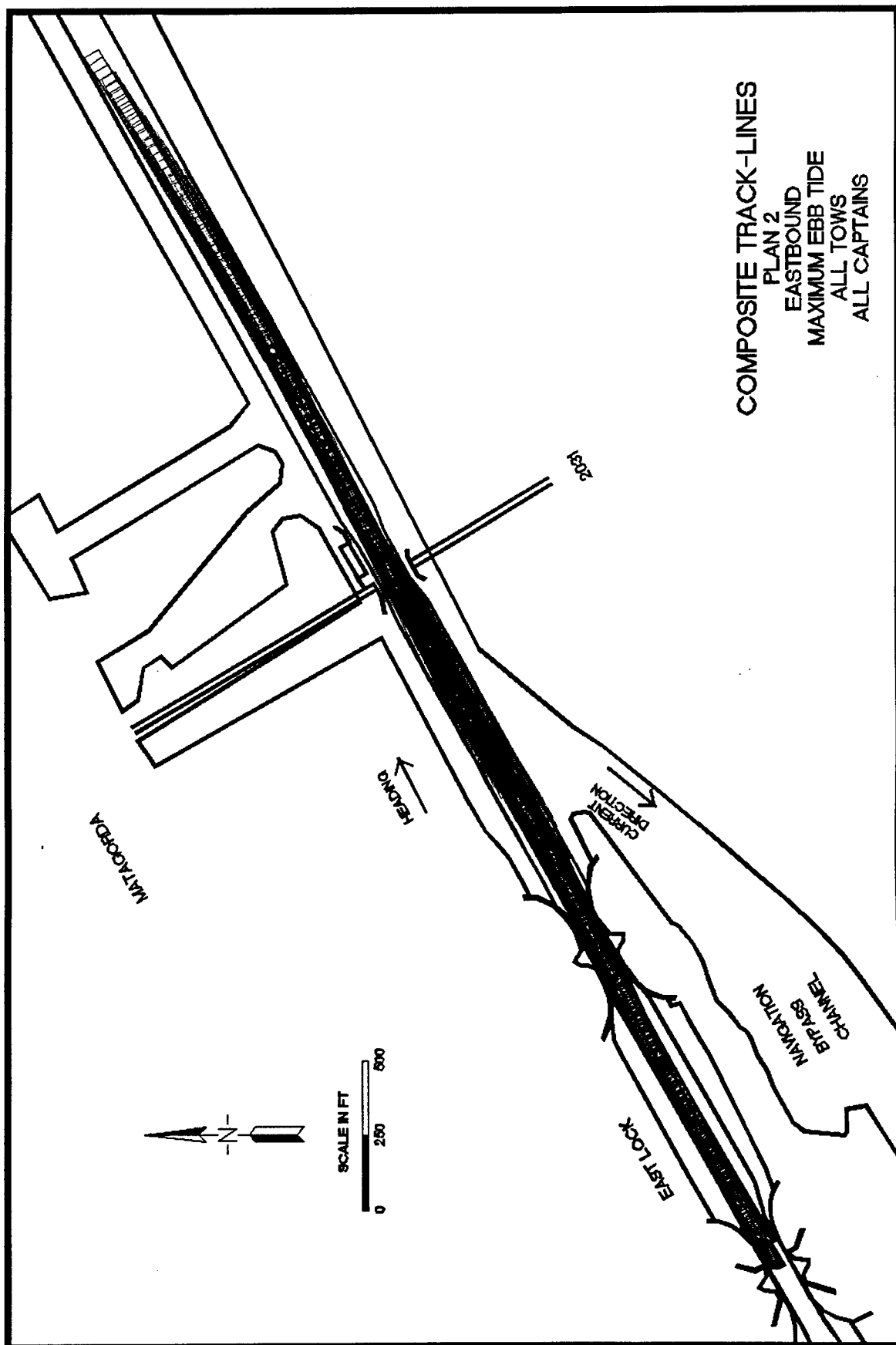
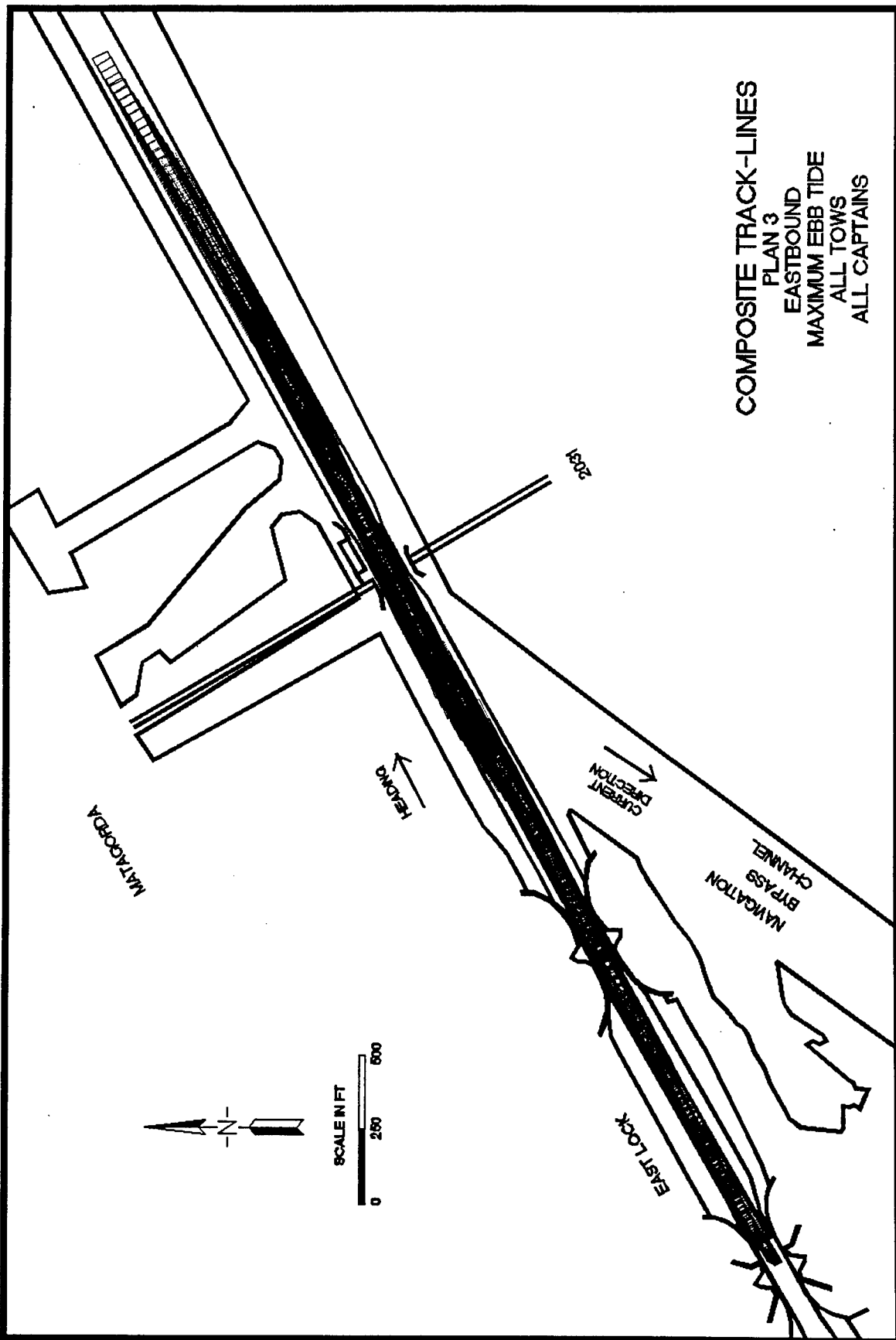


Plate 12



COMPOSITE TRACK-LINES
PLAN 3
EASTBOUND
MAXIMUM EBB TIDE
ALL TOWS
ALL CAPTAINS

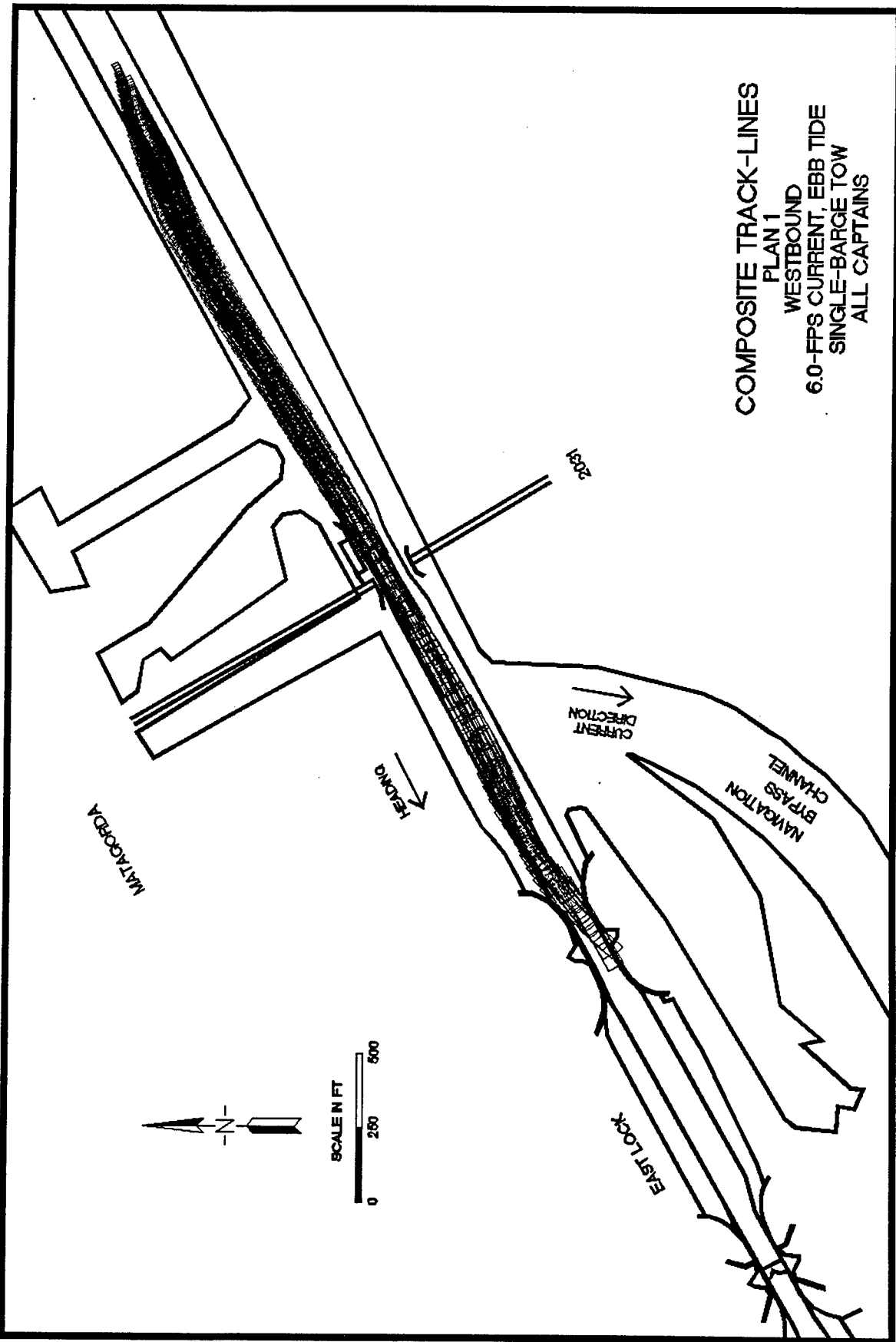
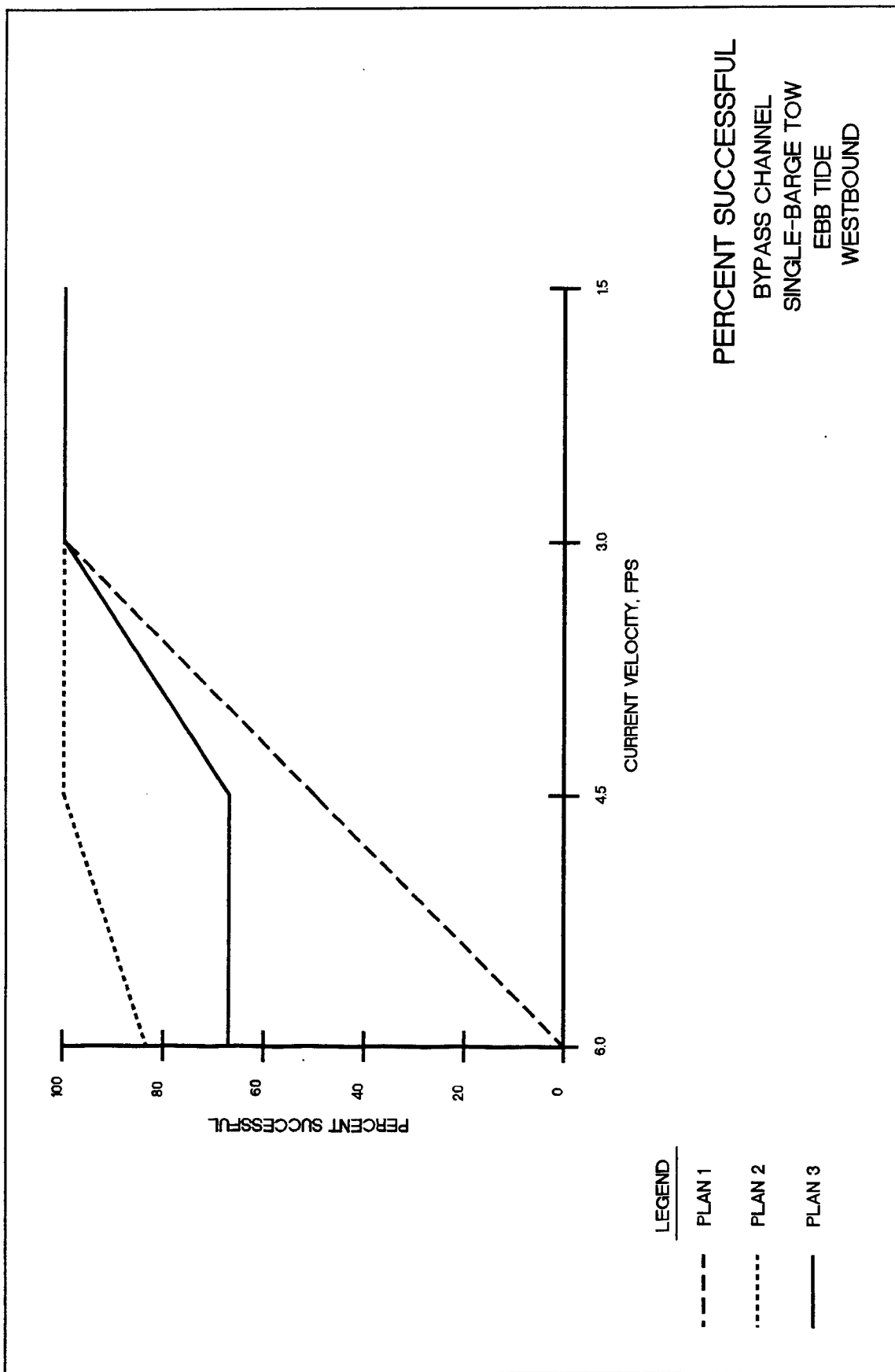


Plate 14



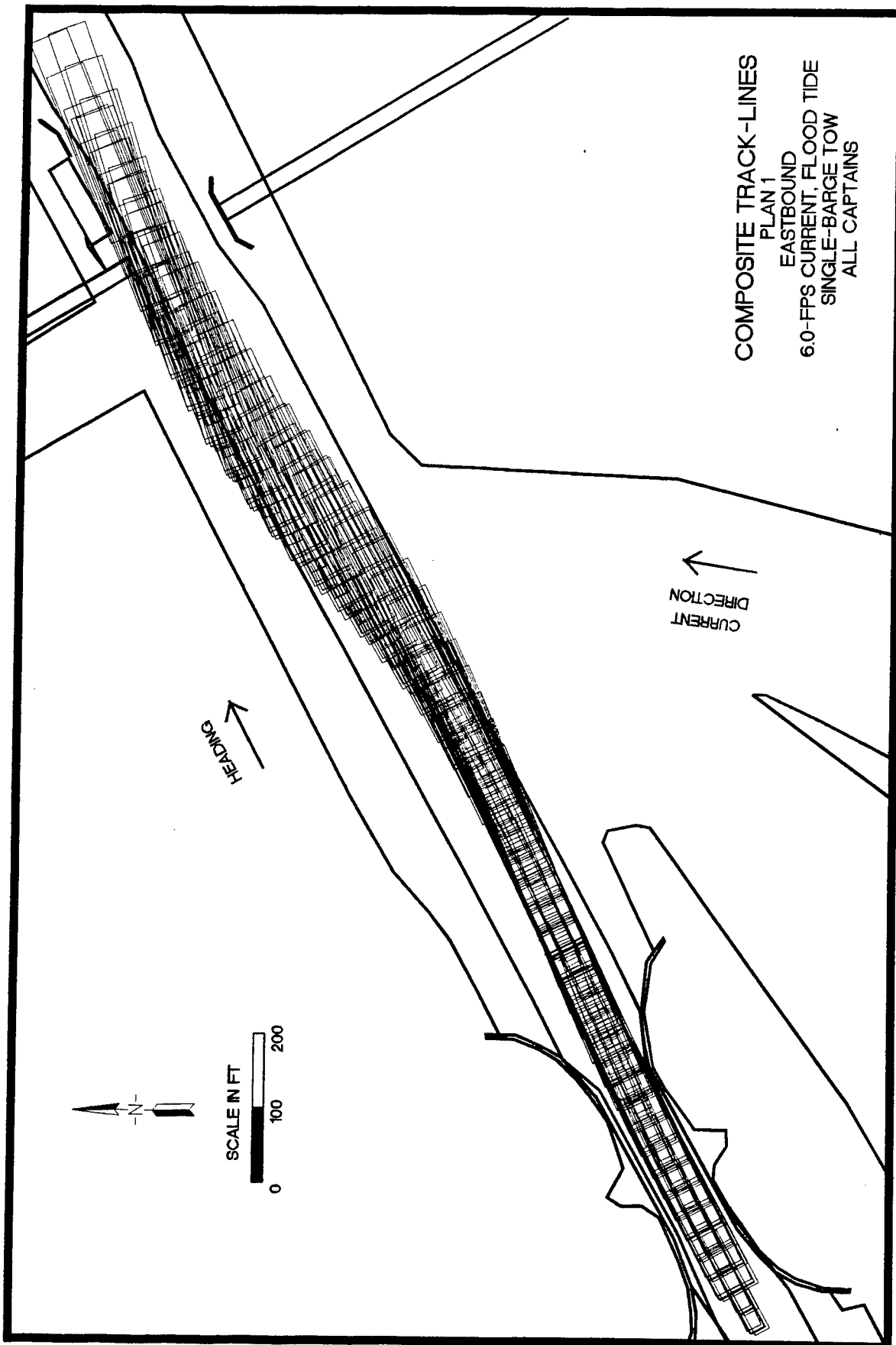


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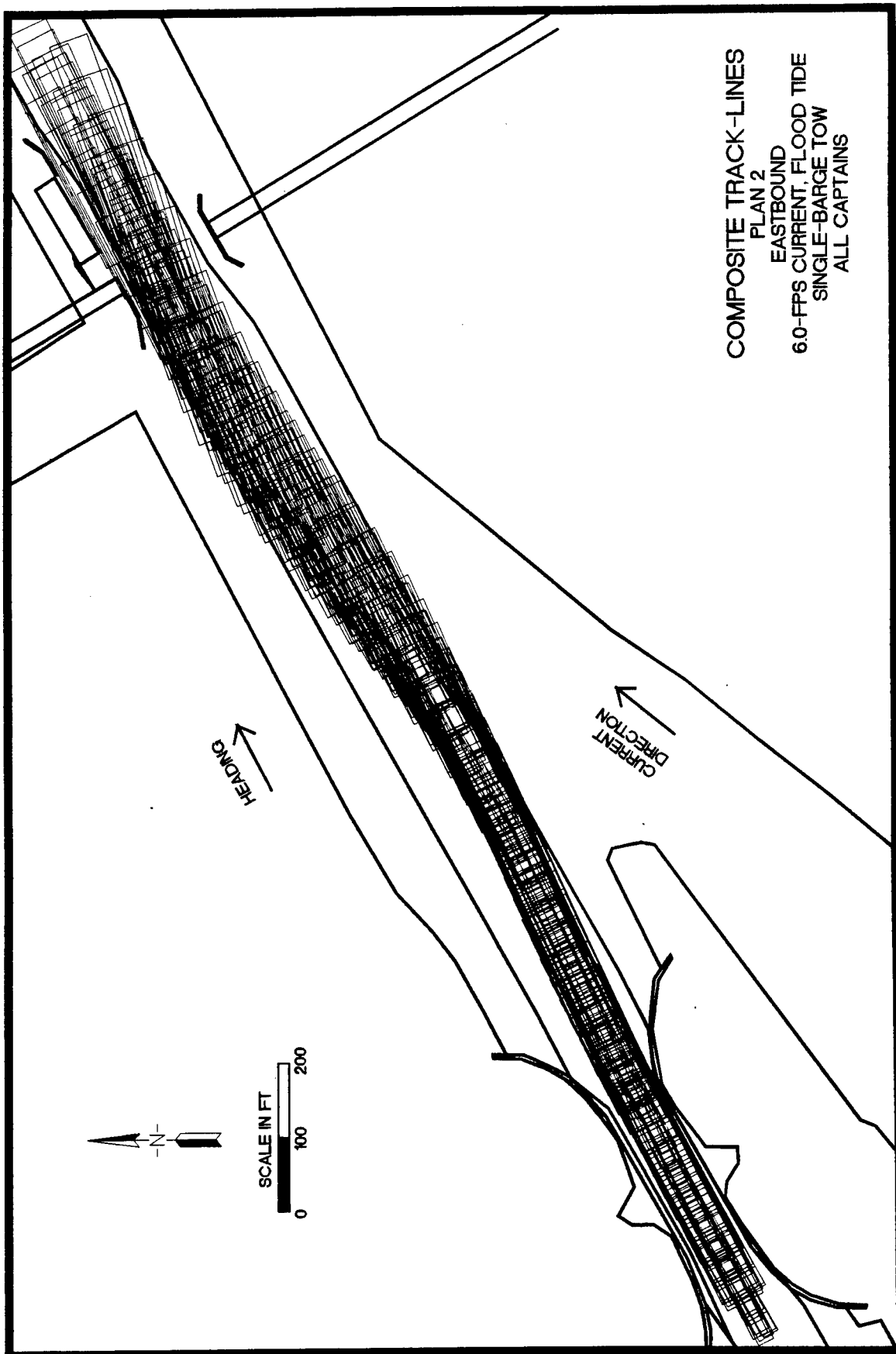
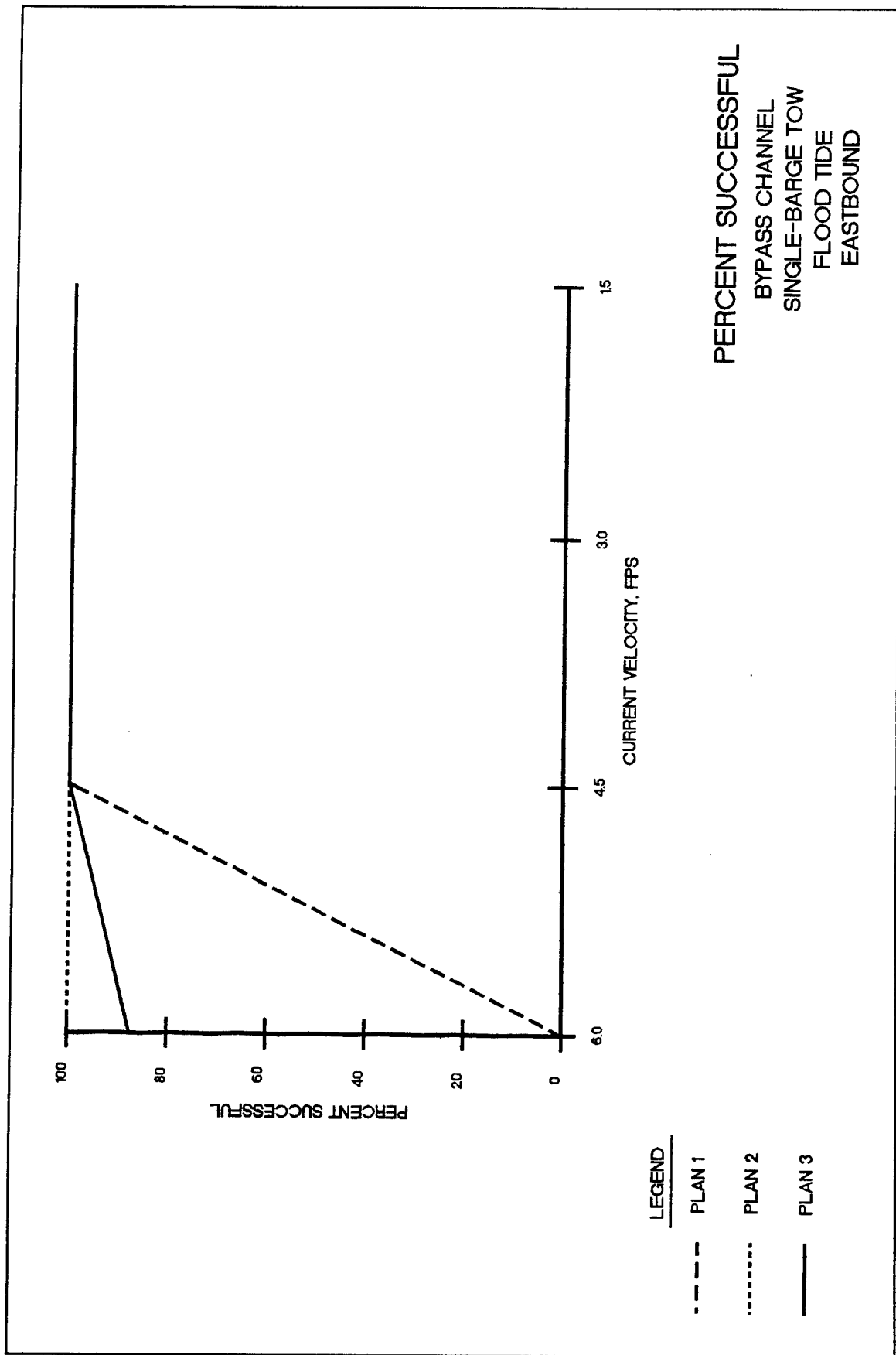


Plate 17



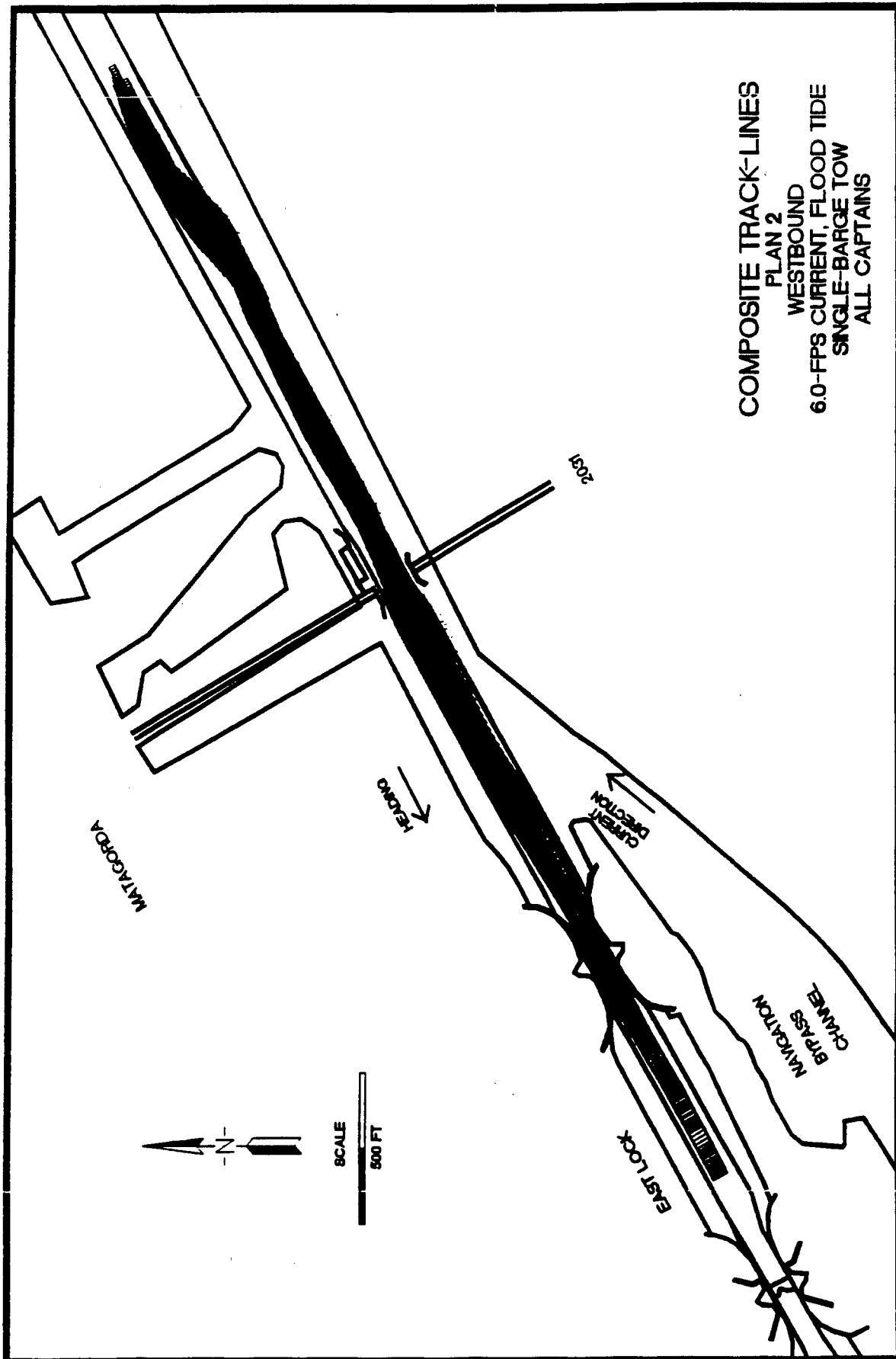
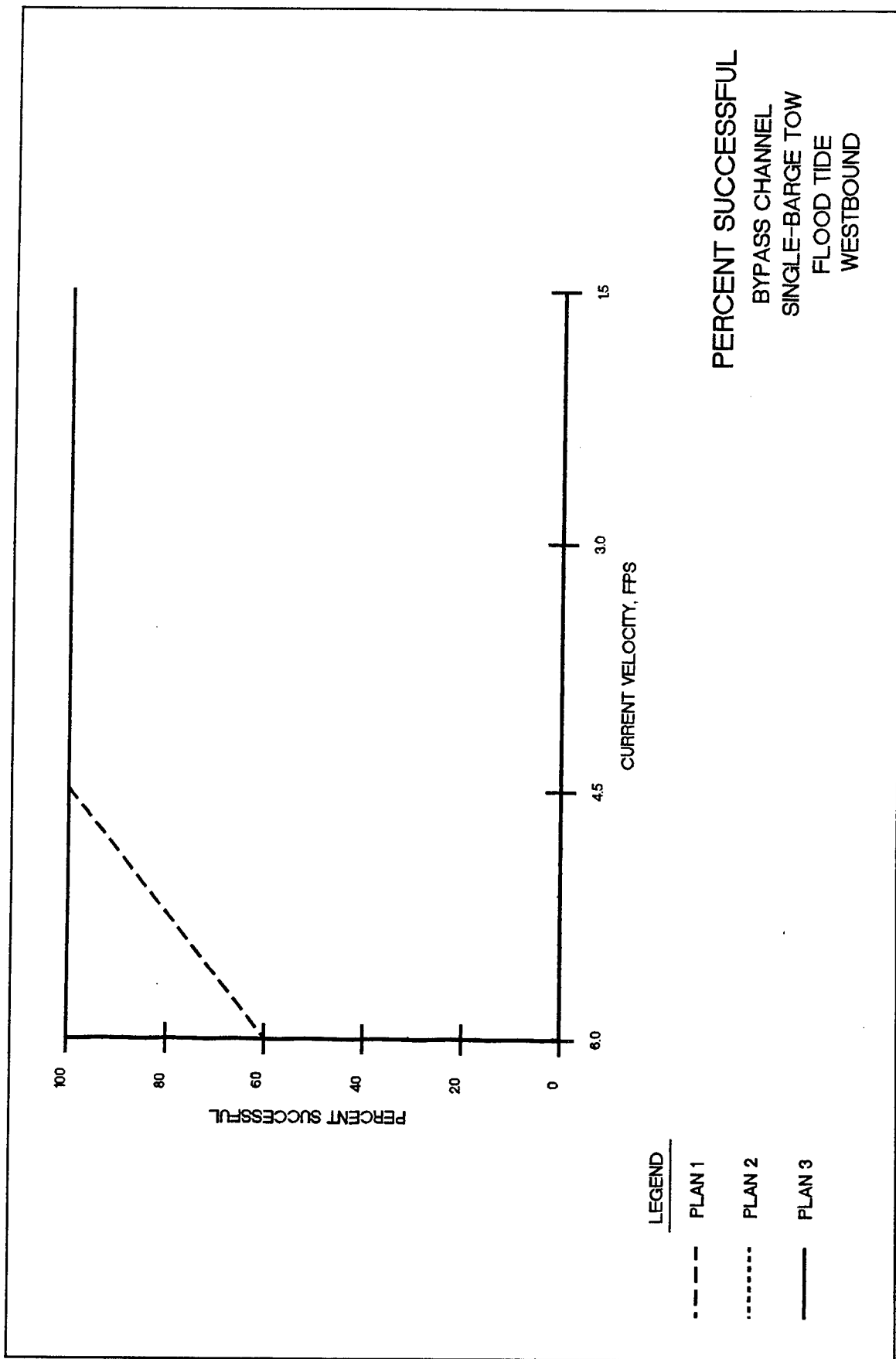
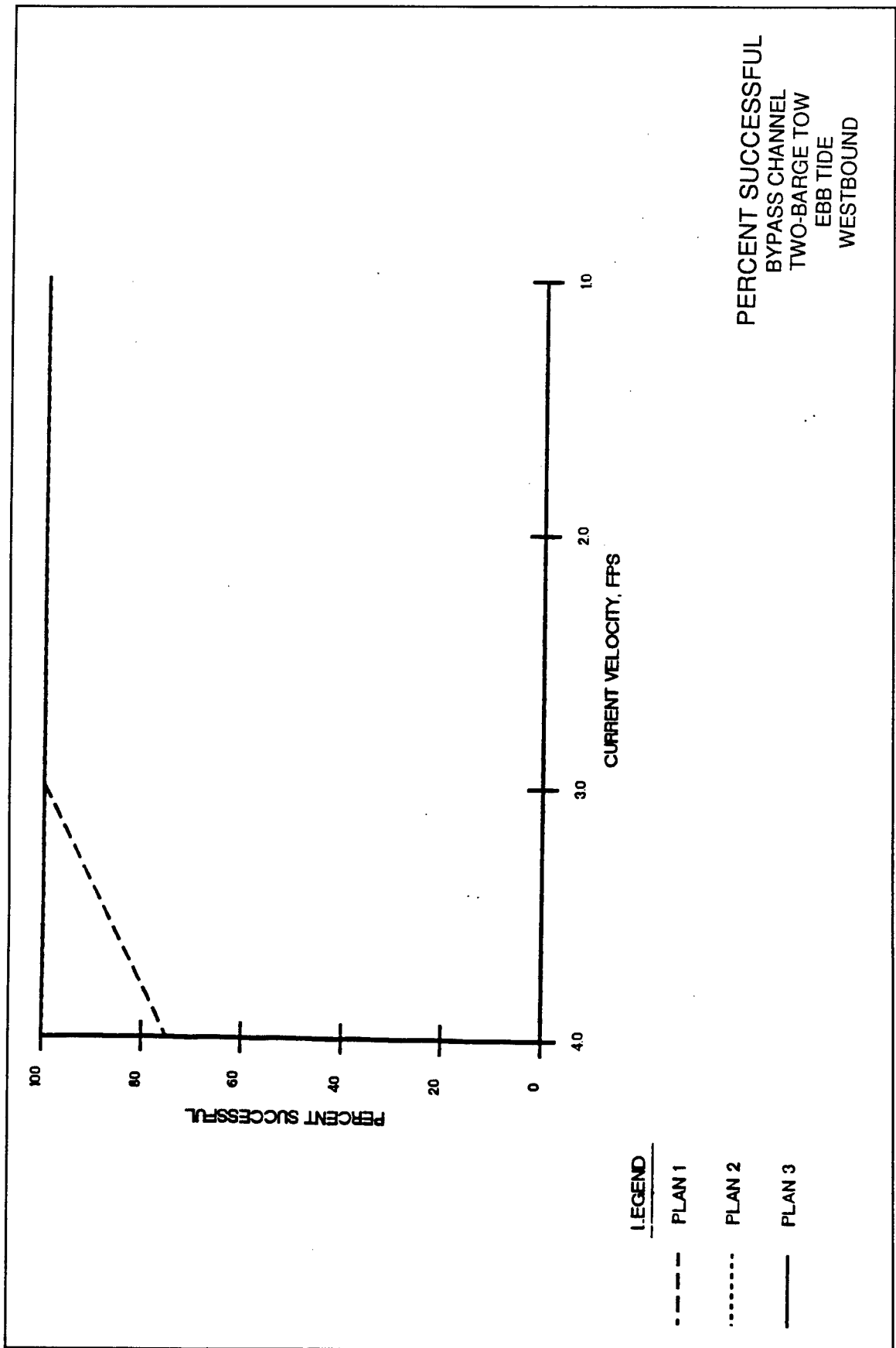


Plate 19





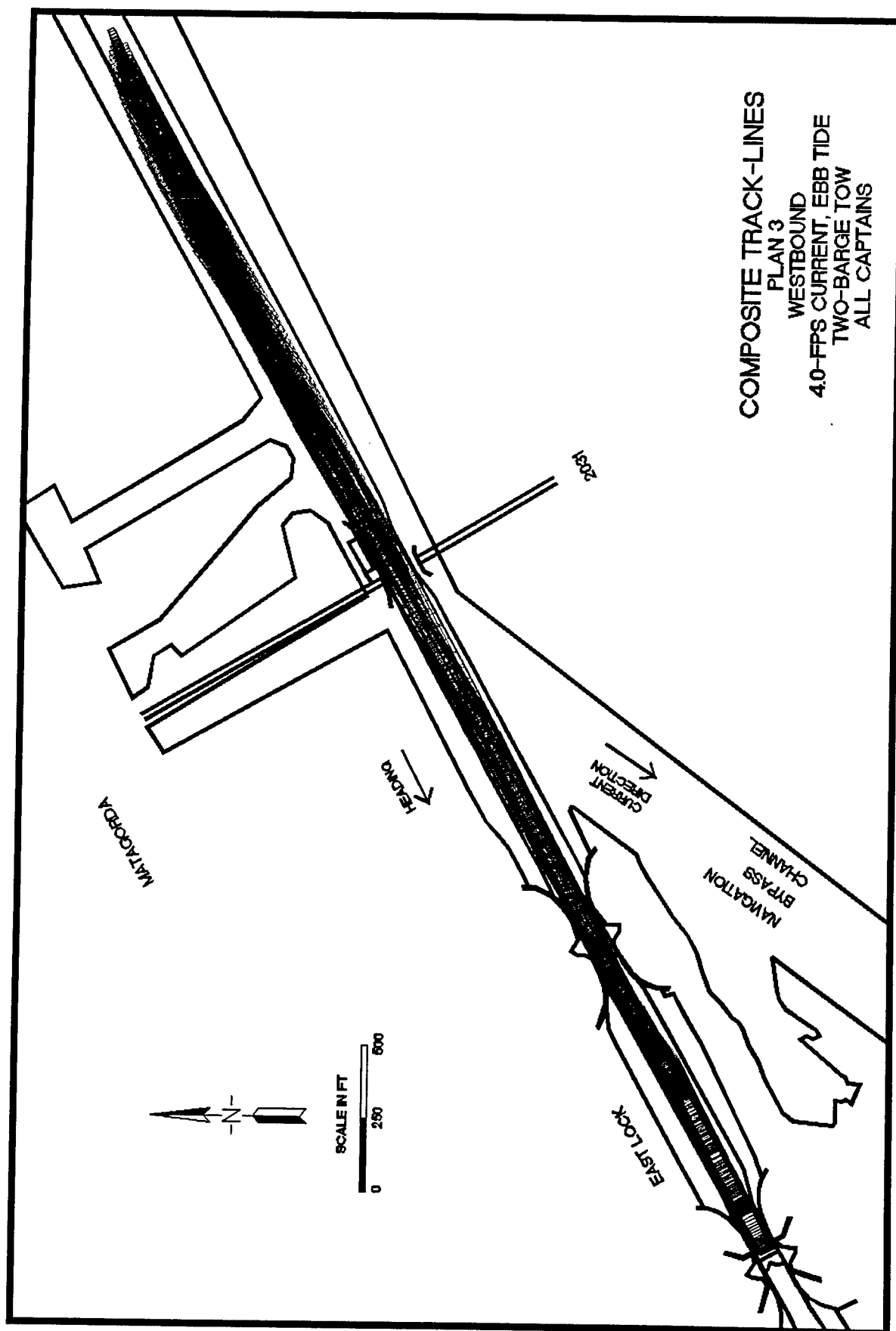


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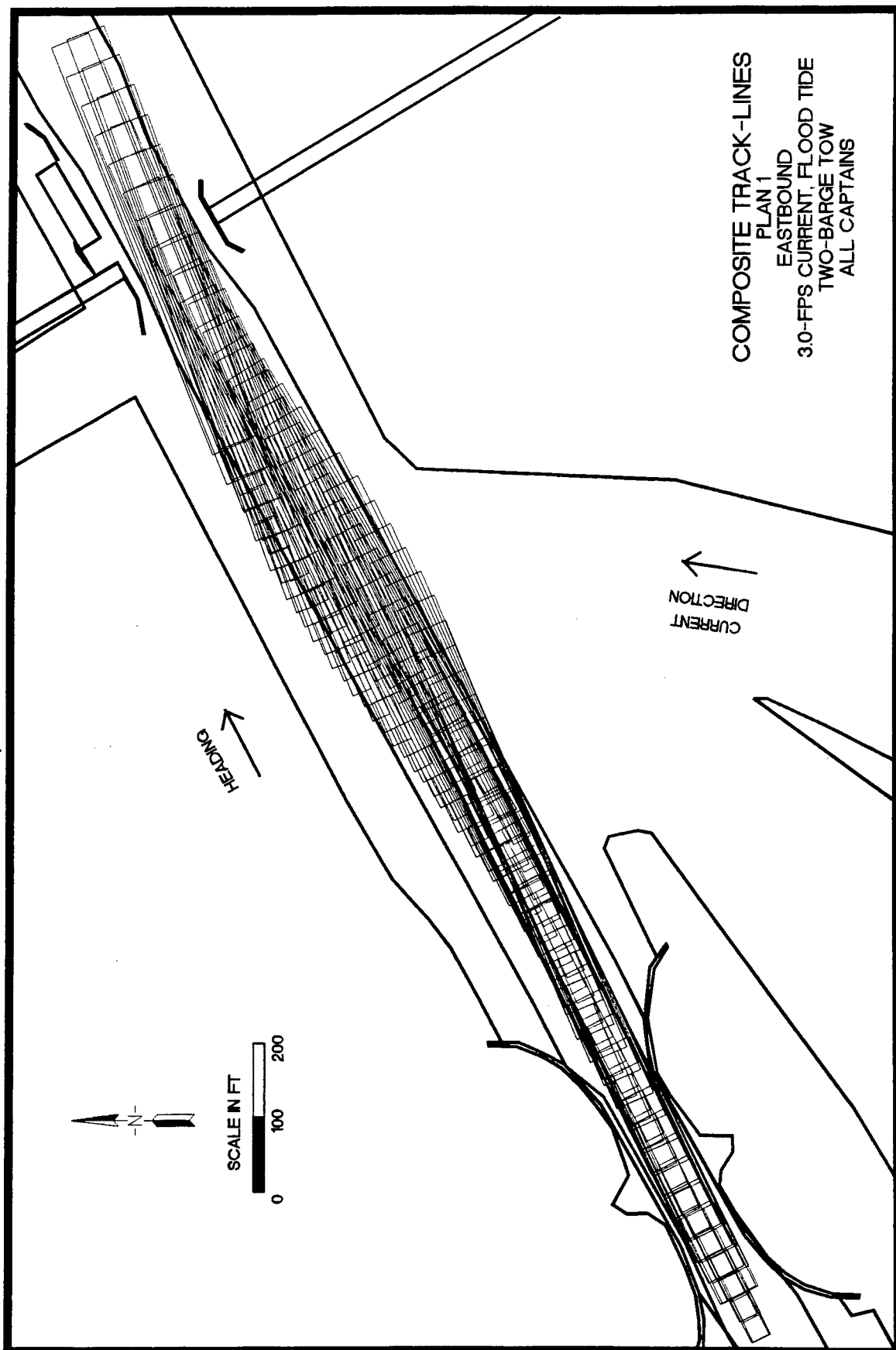


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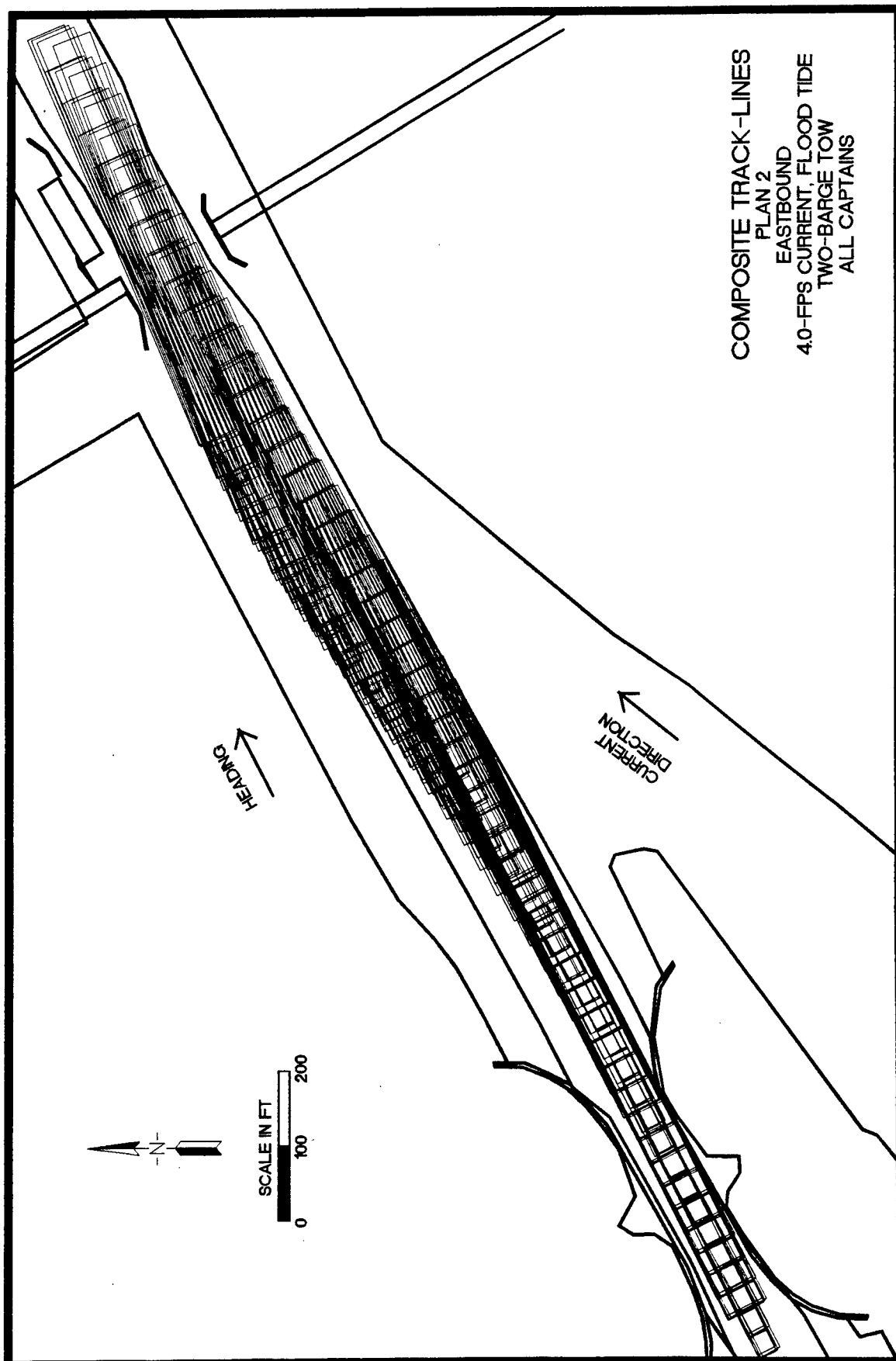


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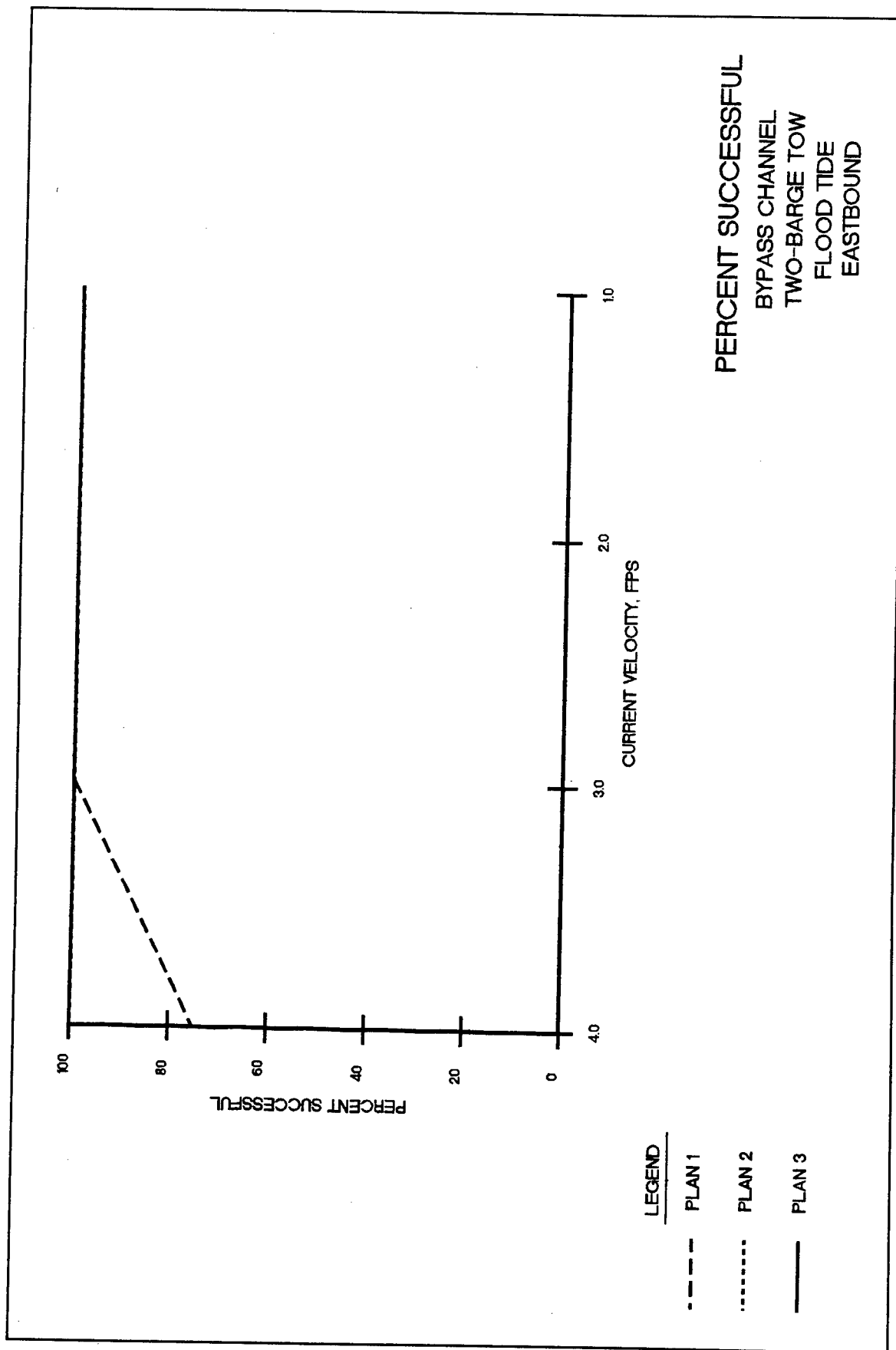
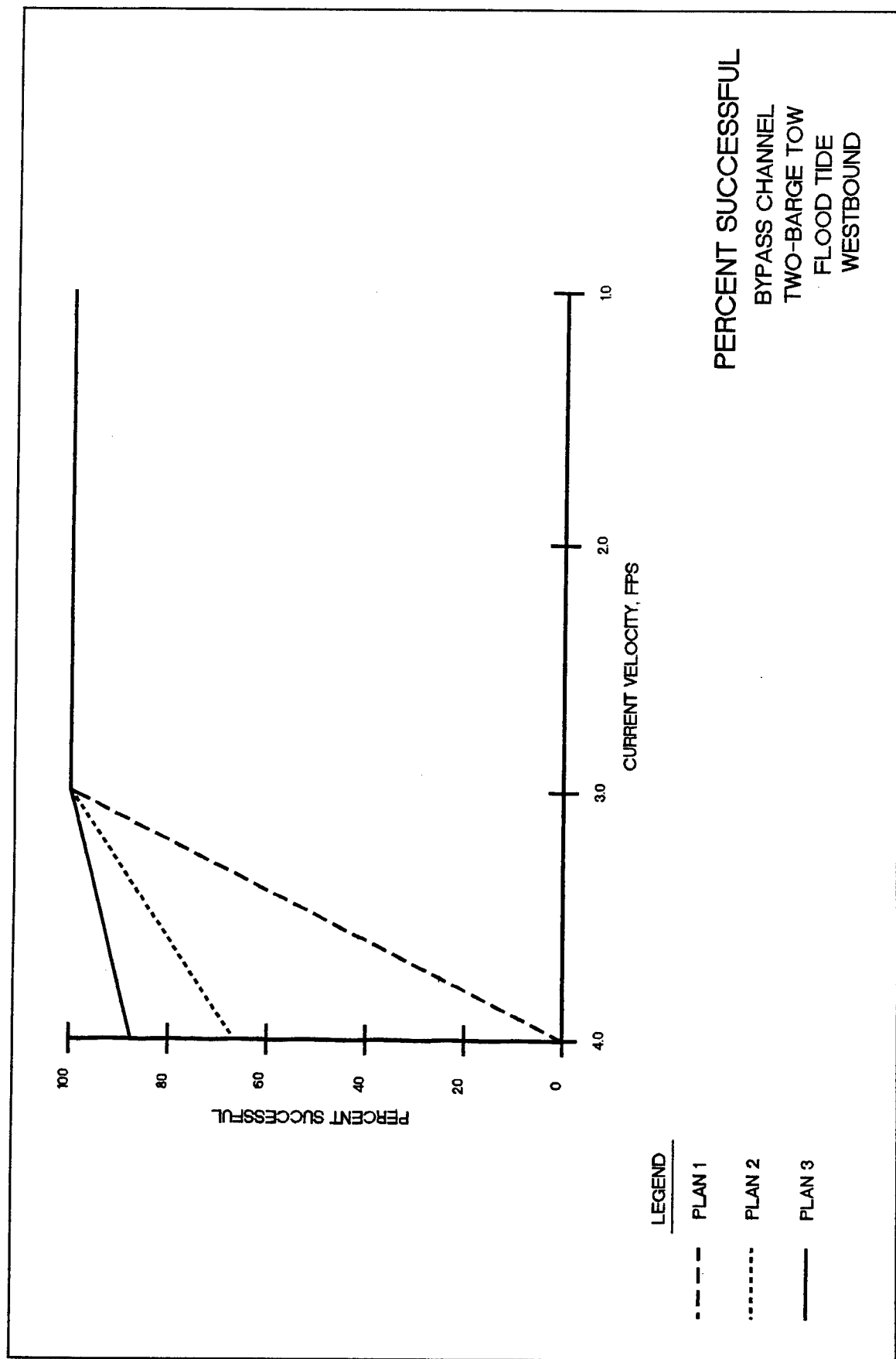


Plate 26



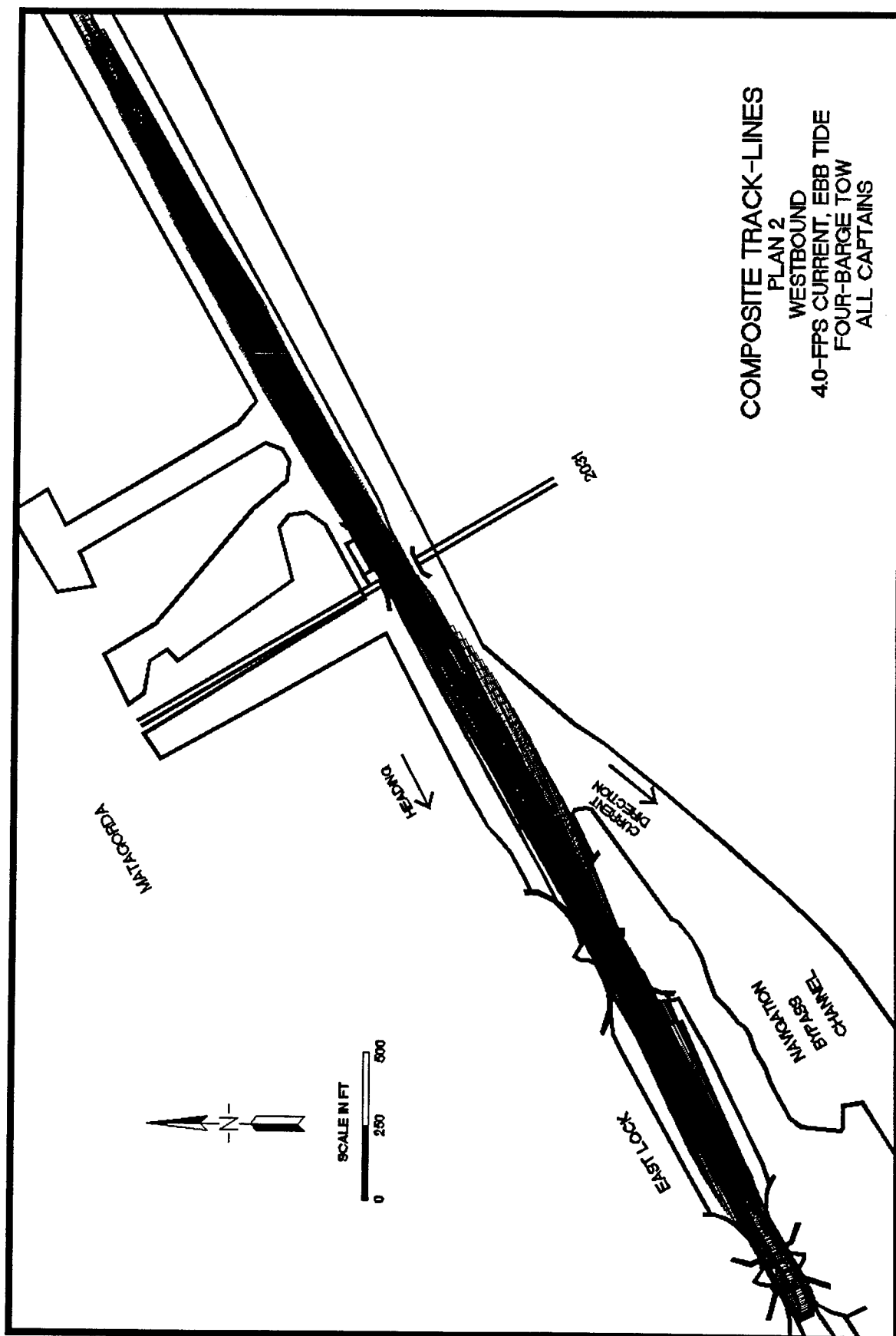


Plate 27

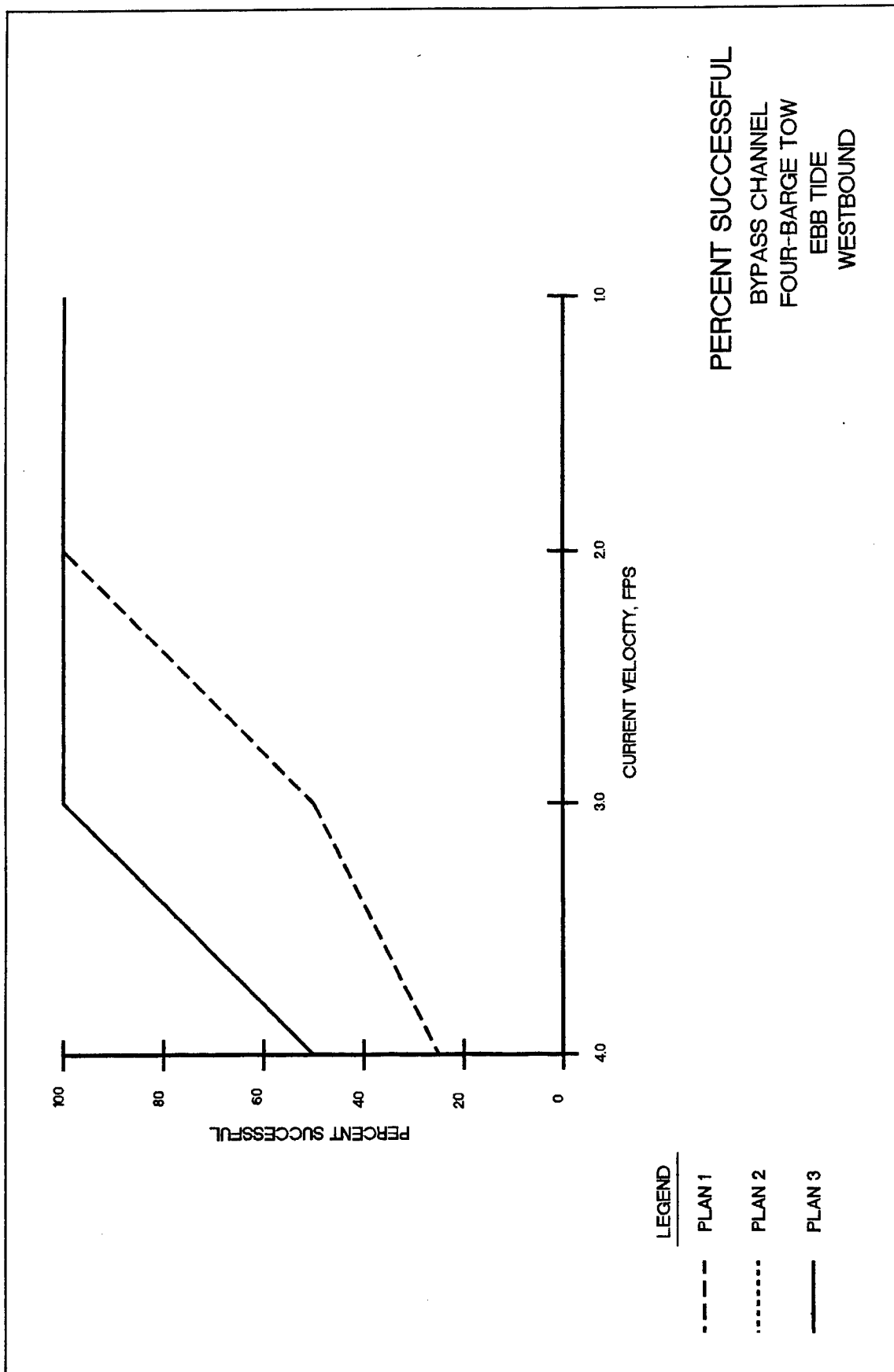
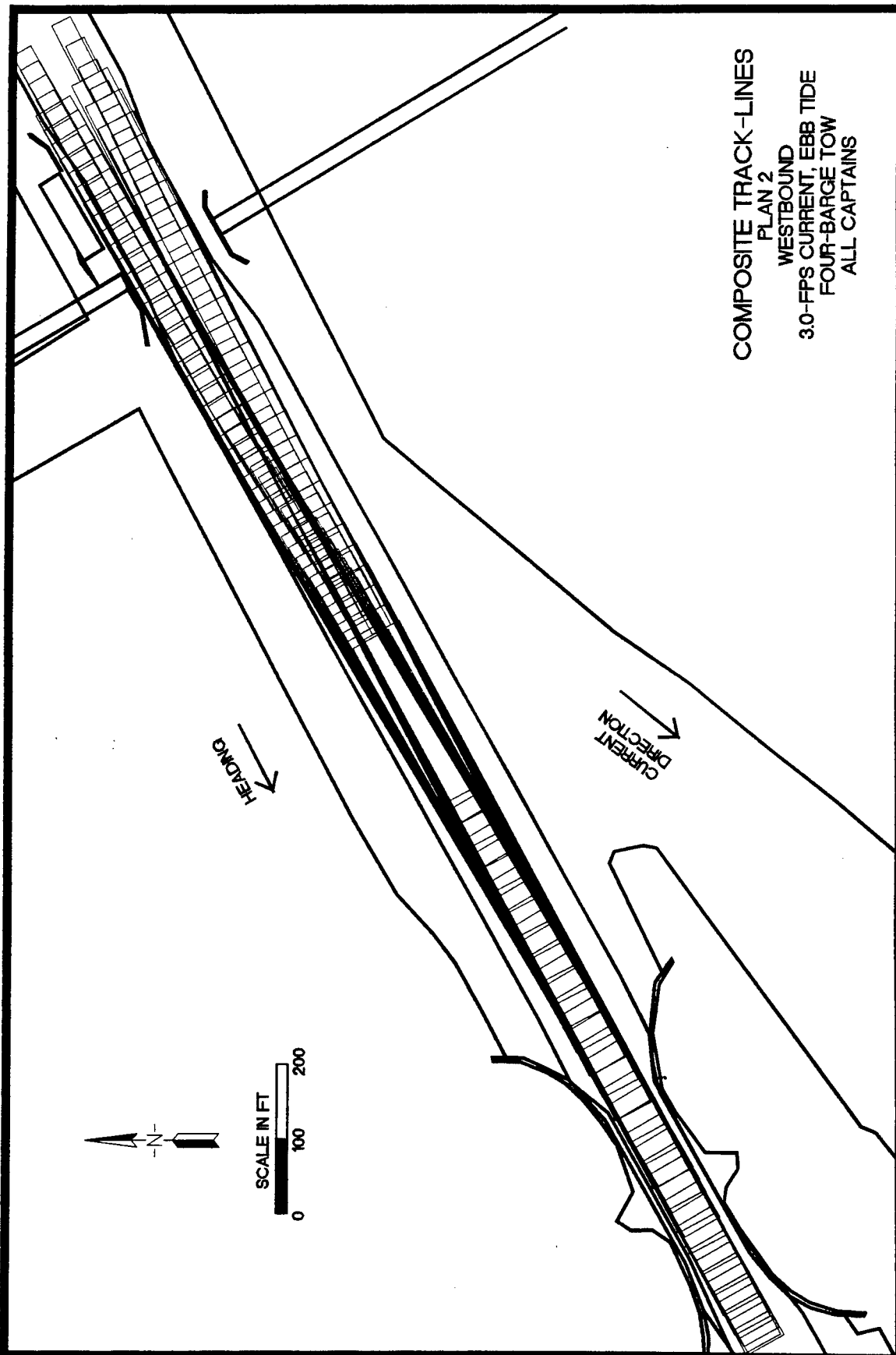


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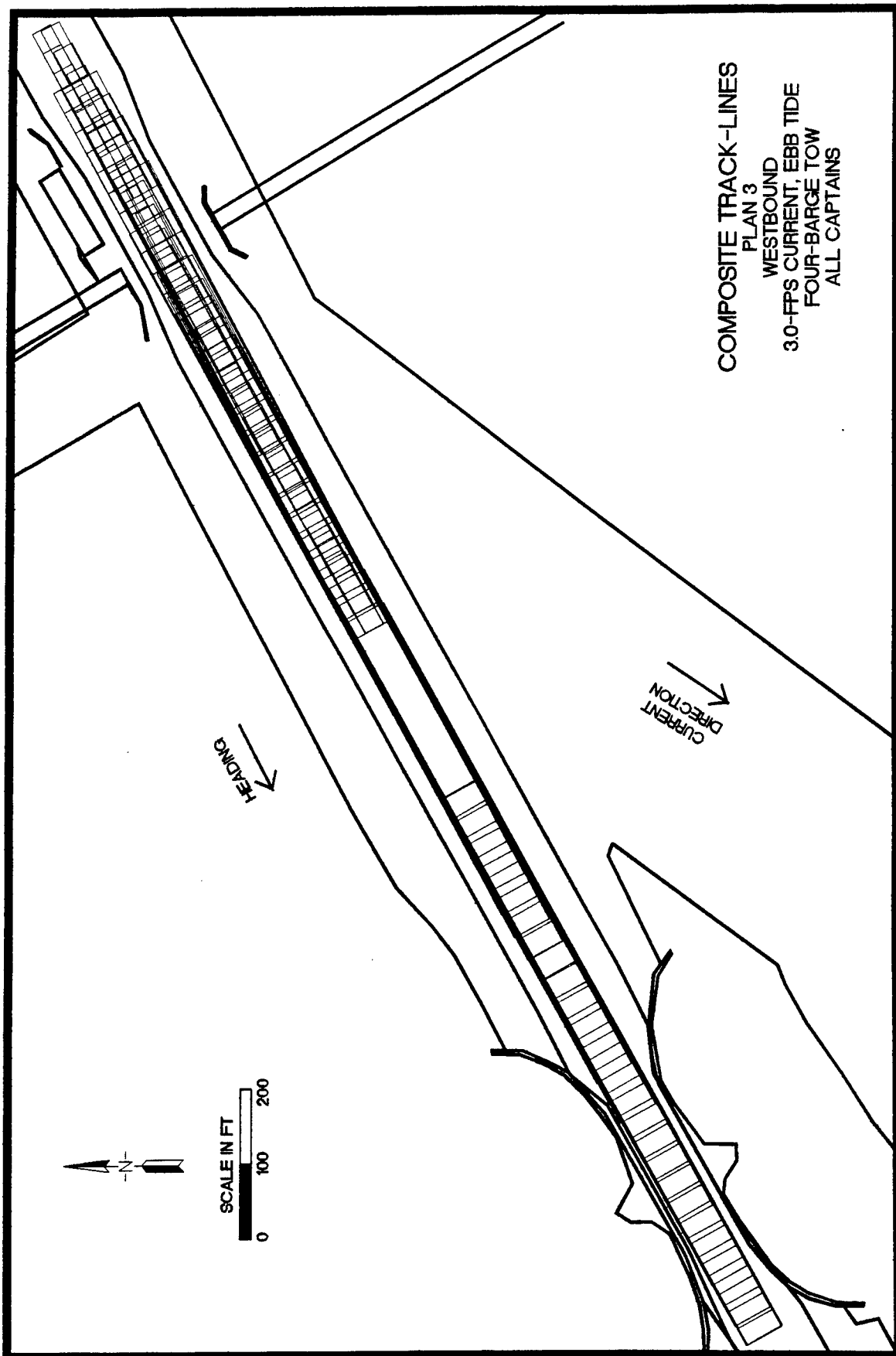
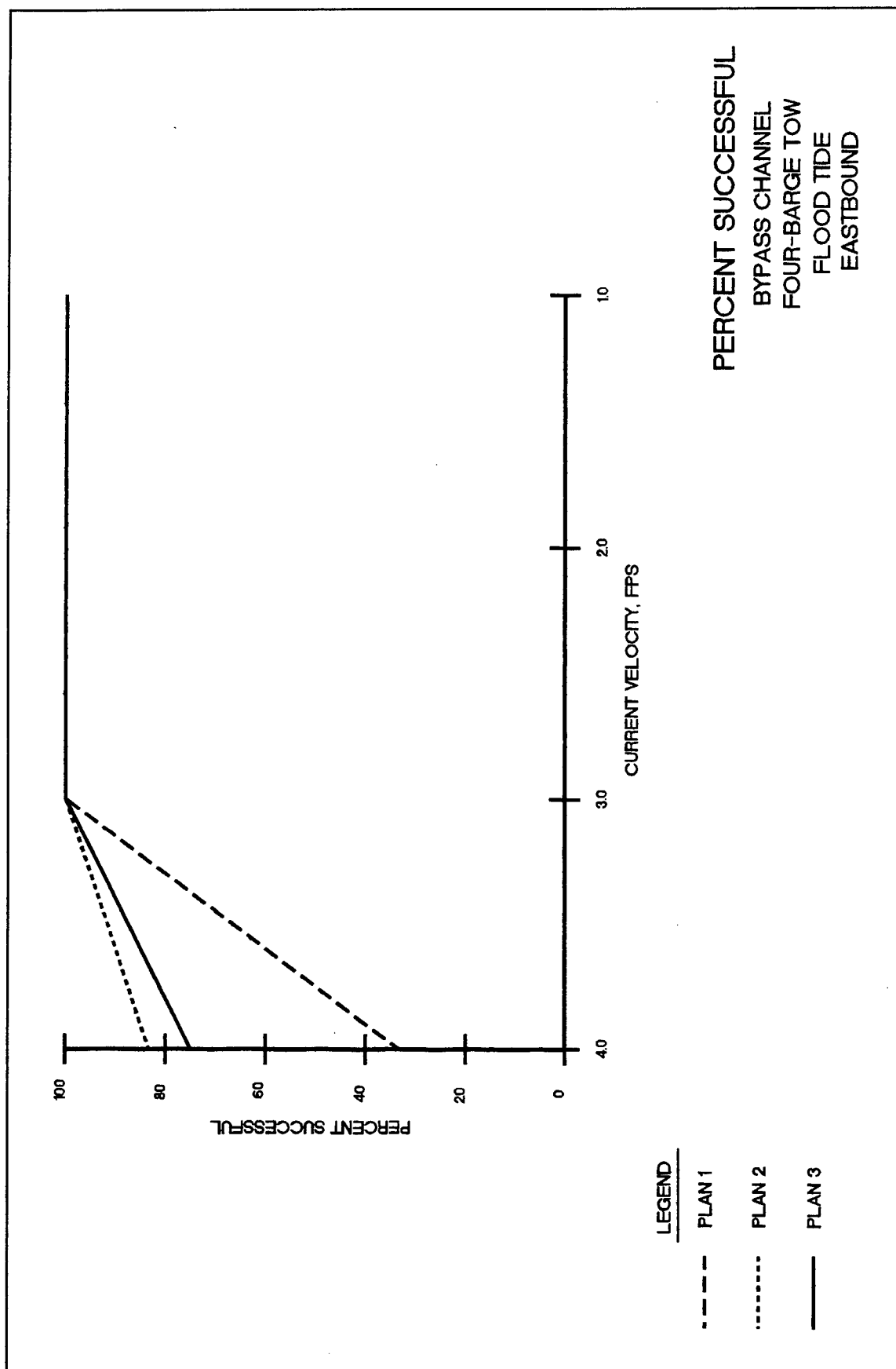


Plate 30



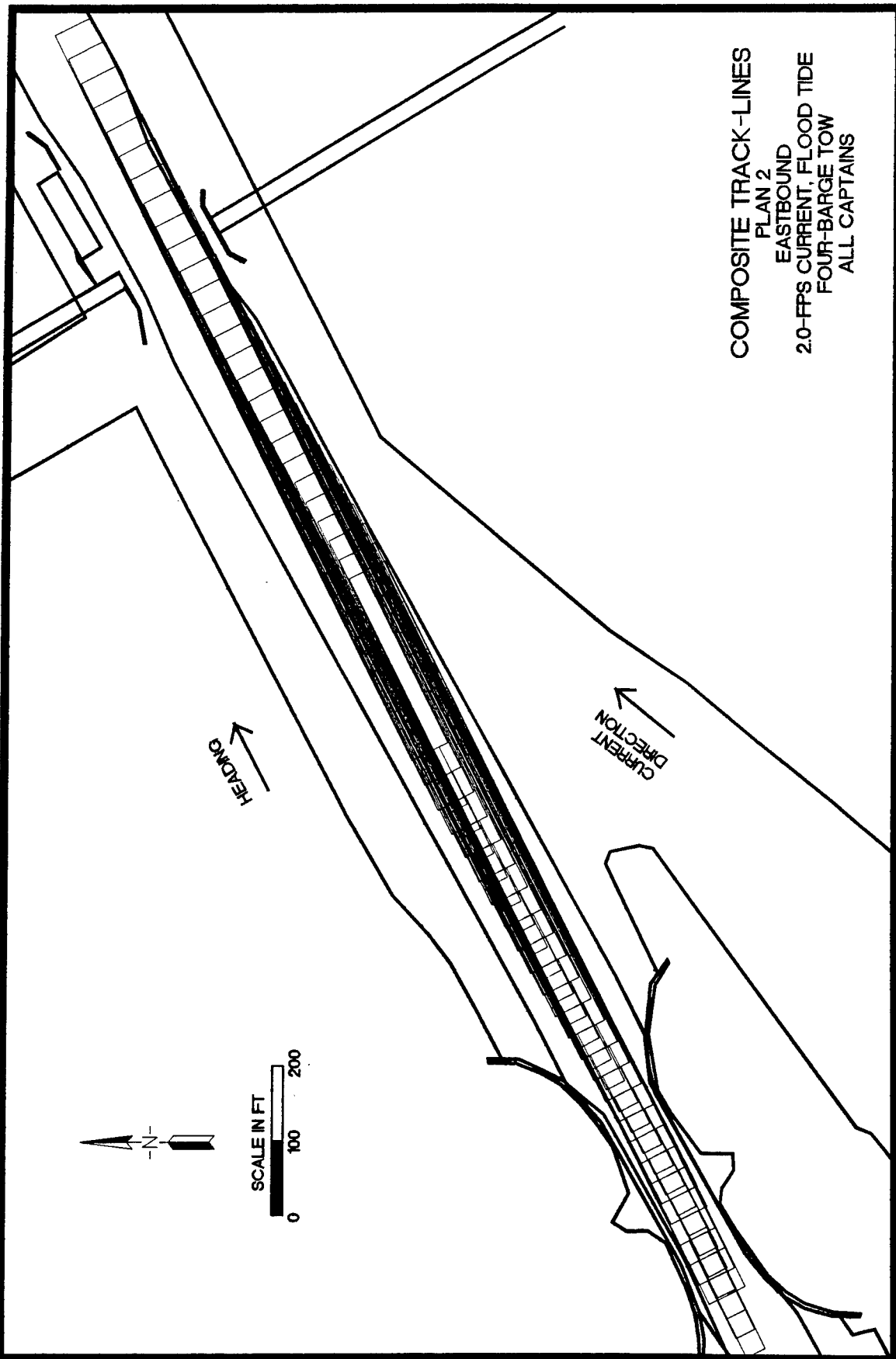
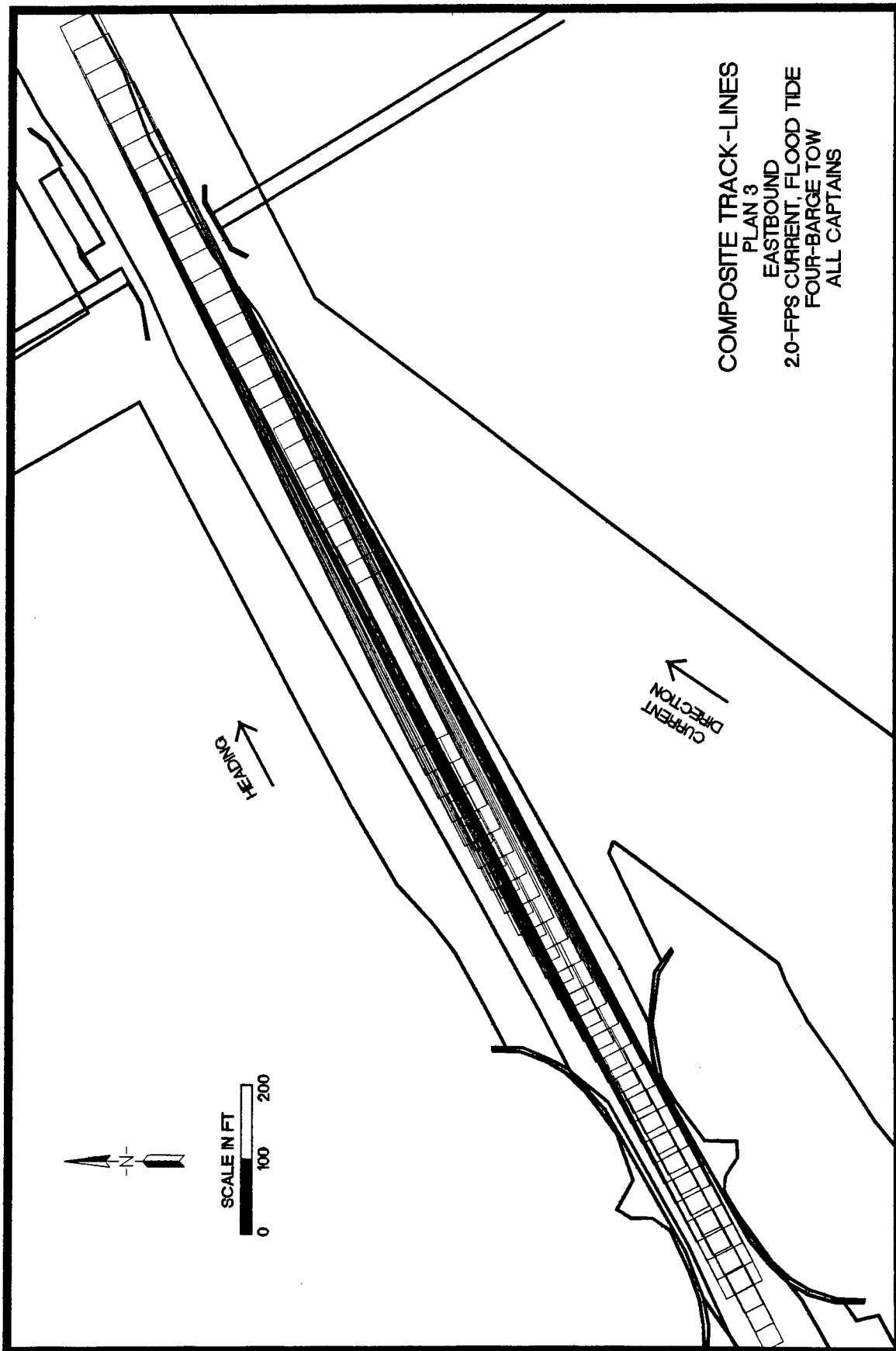


Plate 32



COMPOSITE TRACK-LINES
PLAN 3
EASTBOUND
2.0-FPS CURRENT, FLOOD TIDE
FOUR-BARGE TOW
ALL CAPTAINS

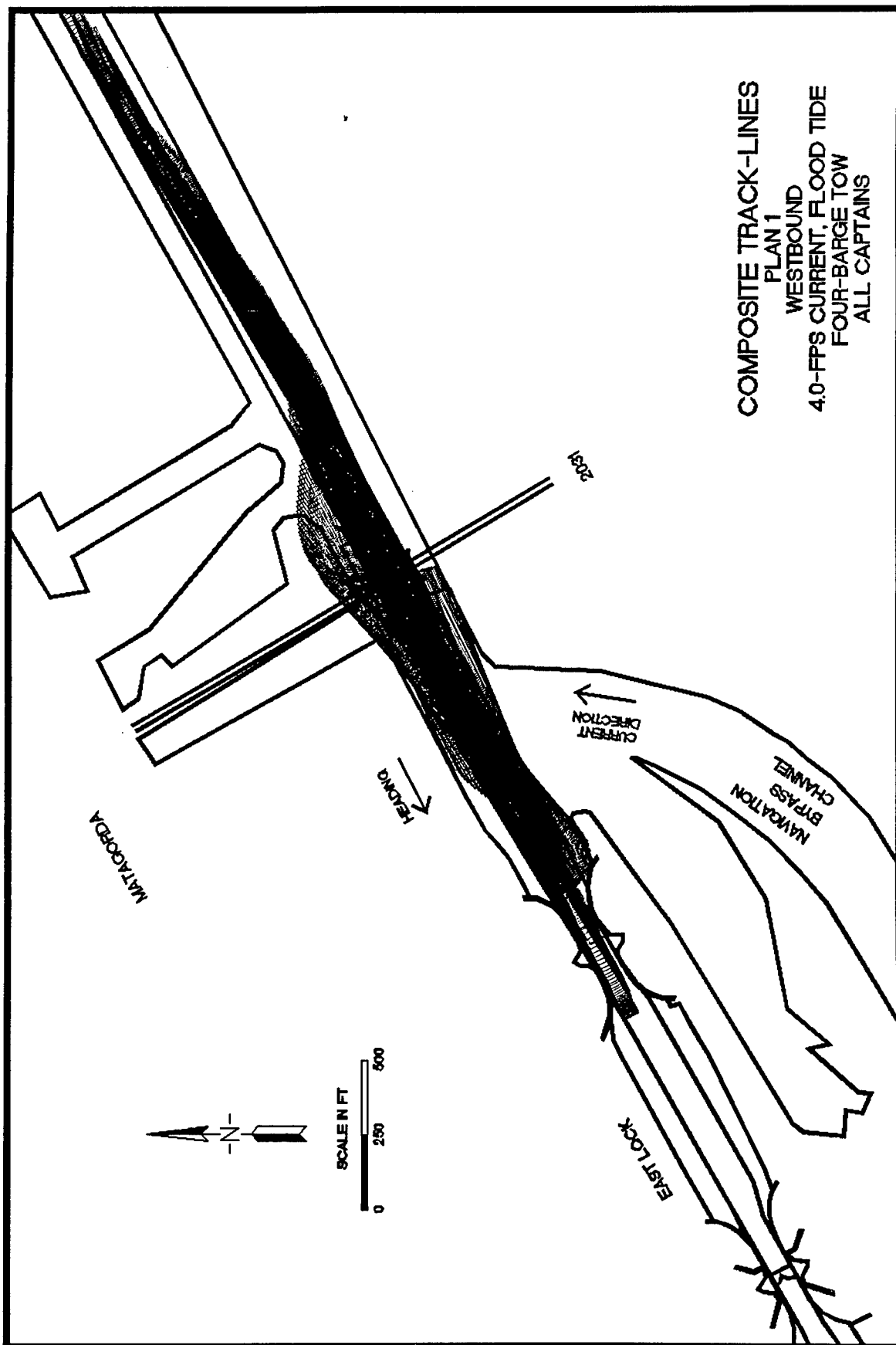


Plate 34

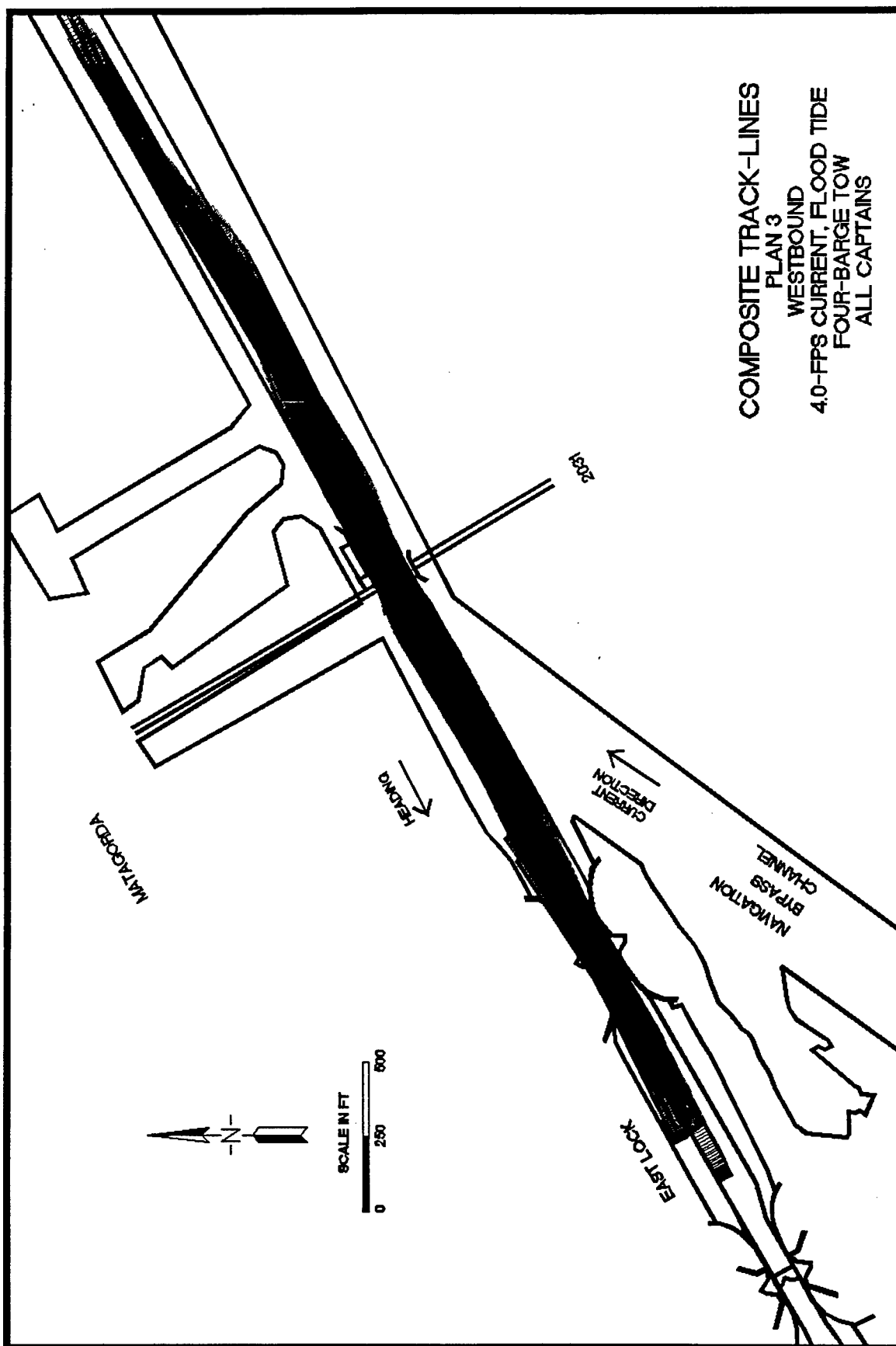


Plate 35

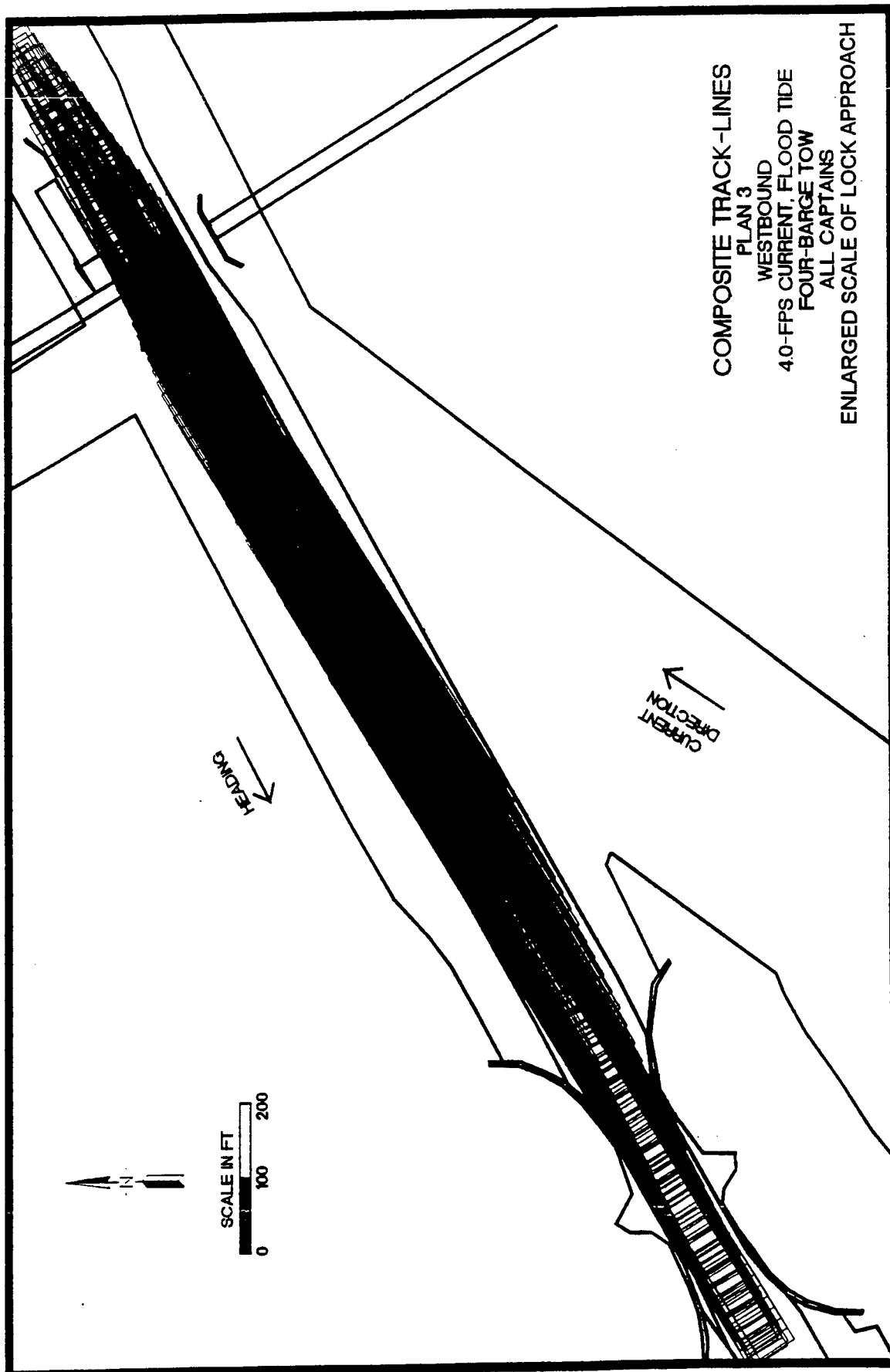
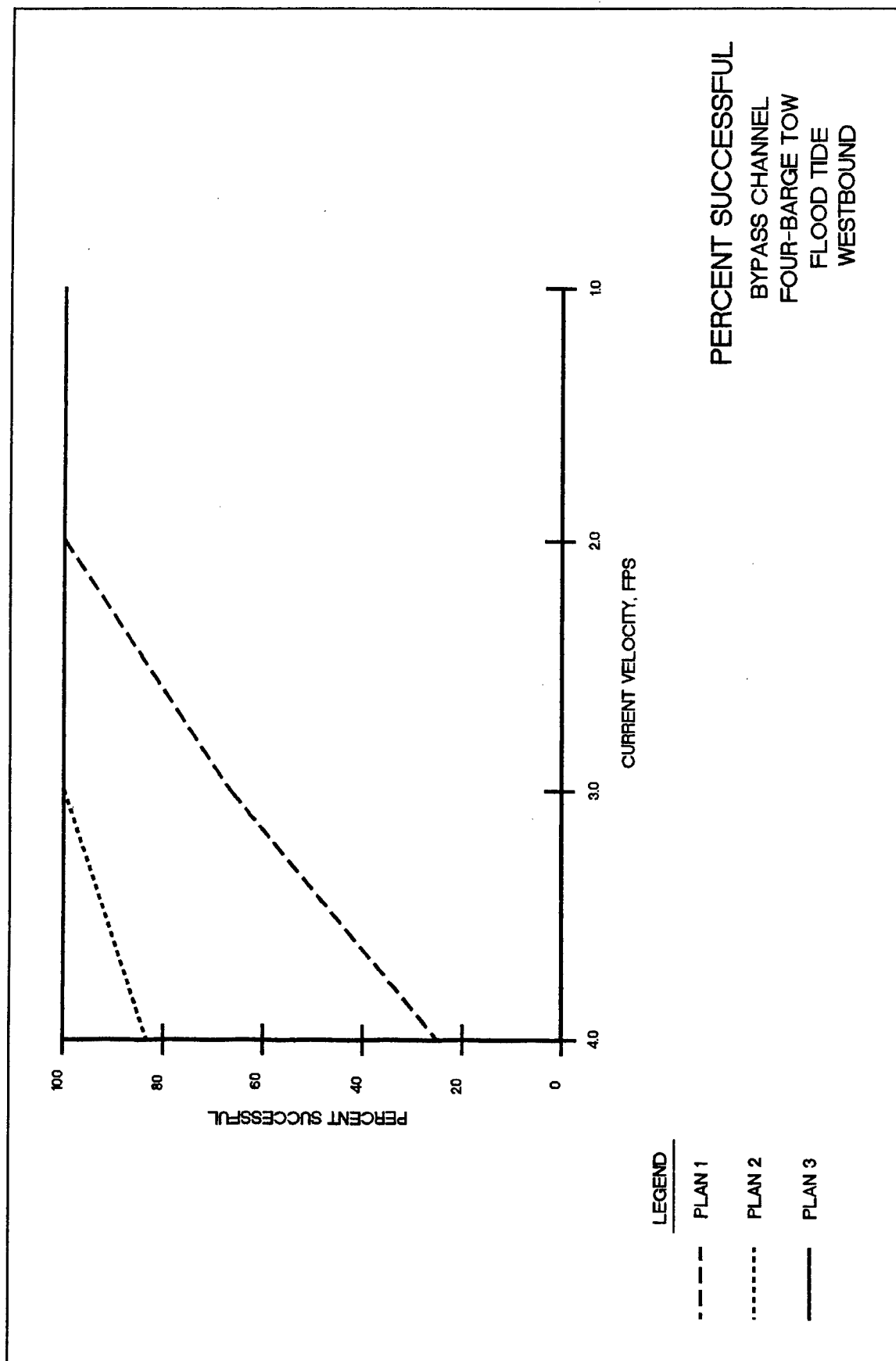


Plate 36



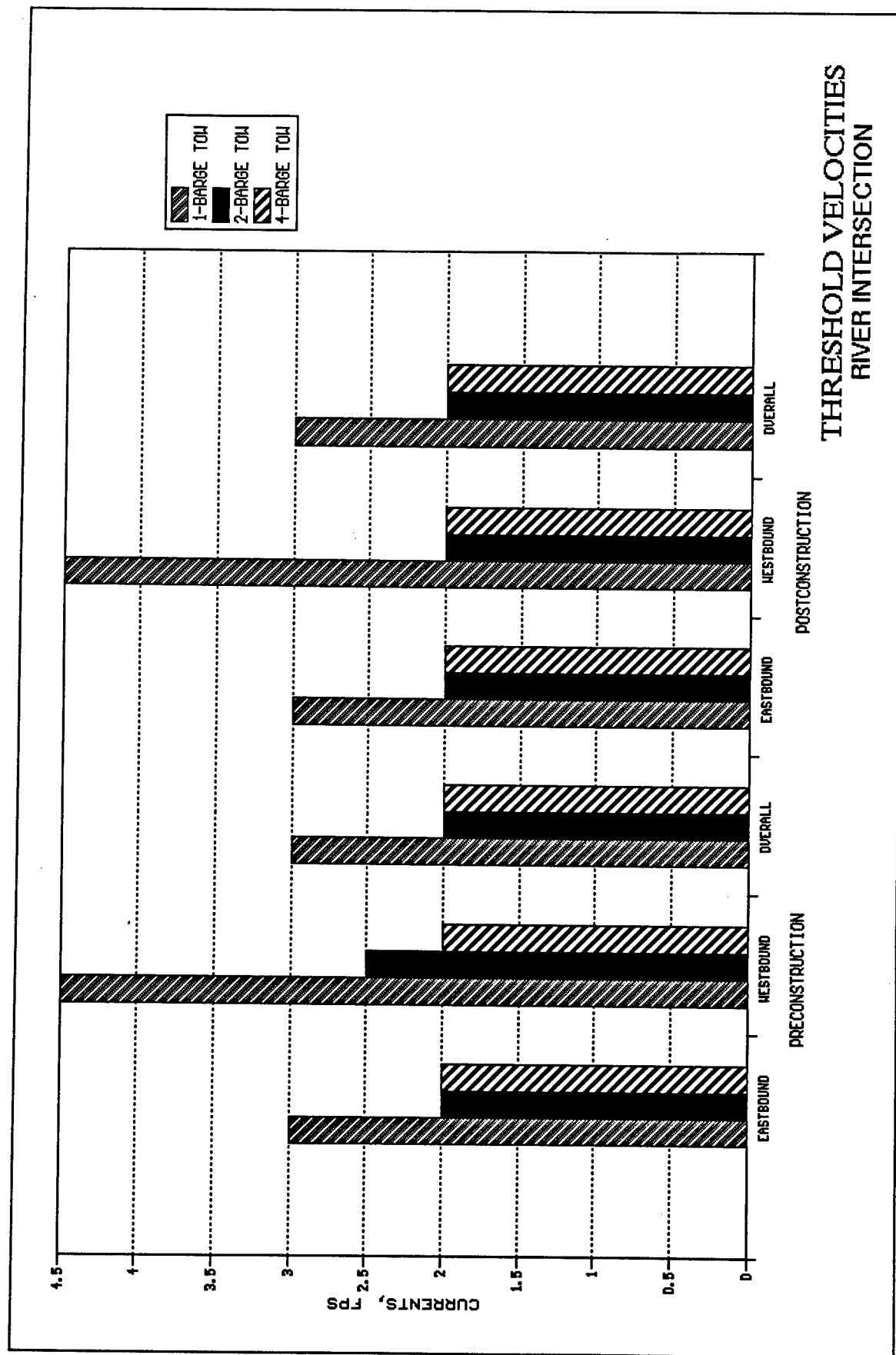
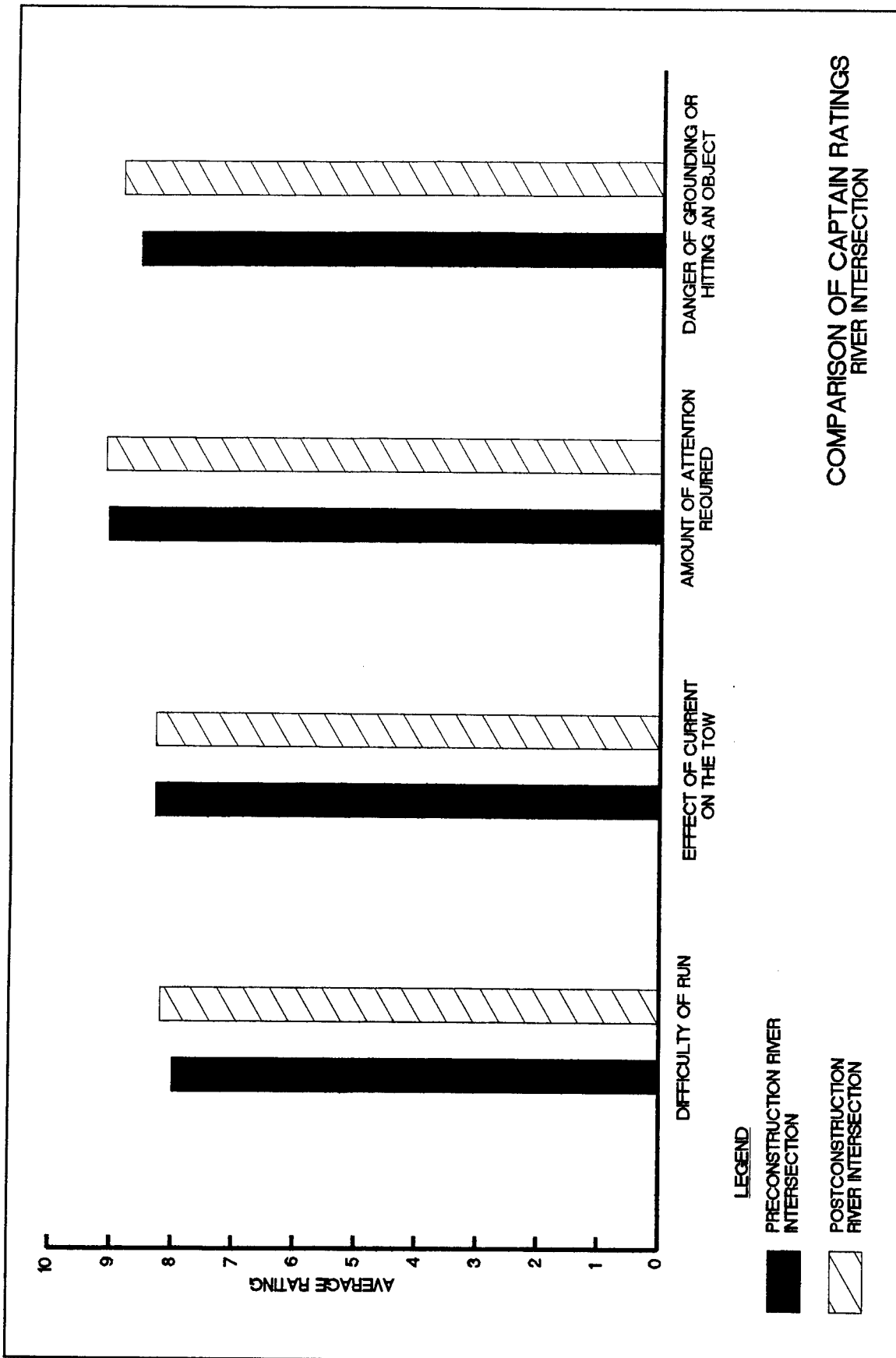
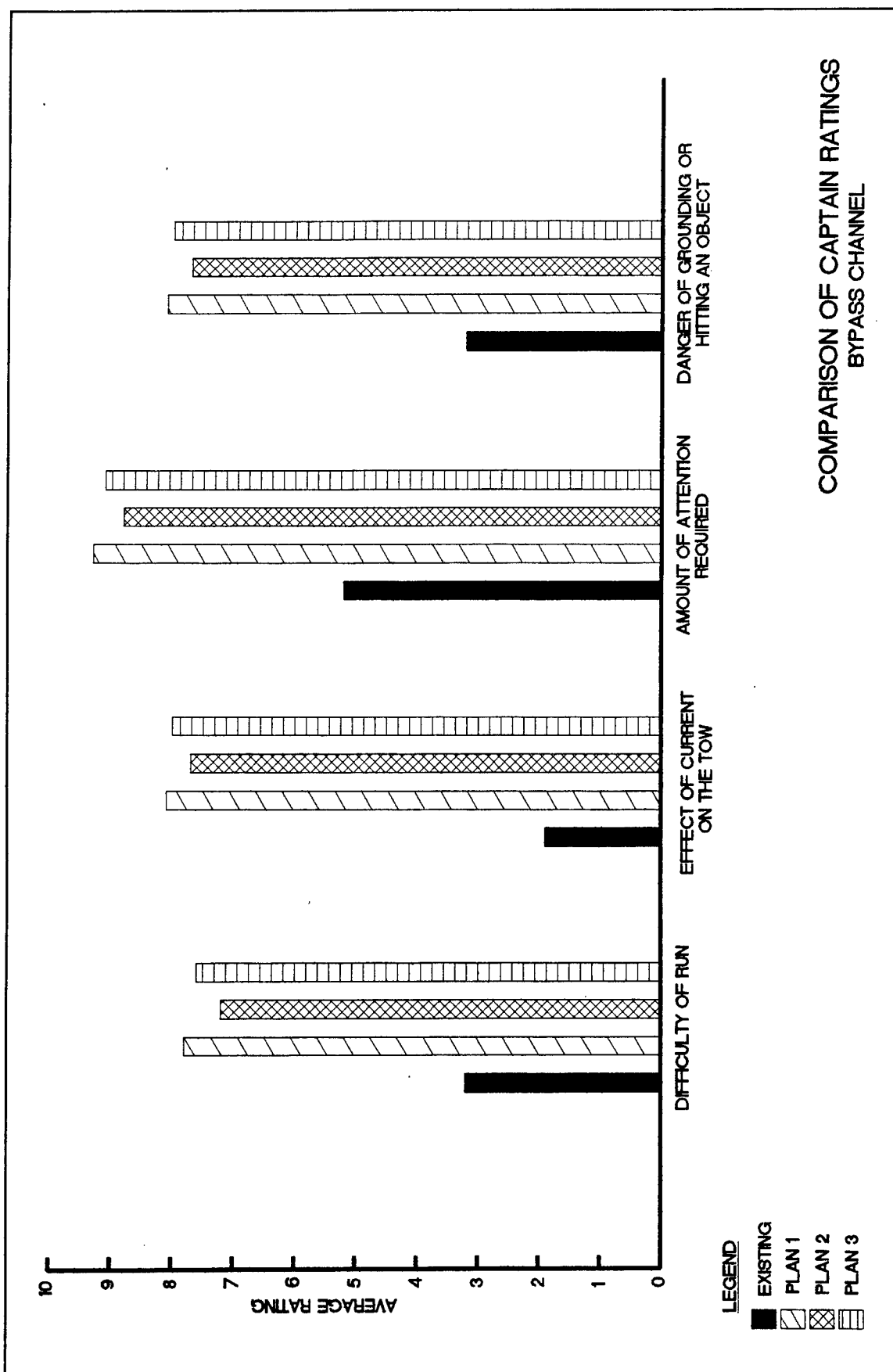
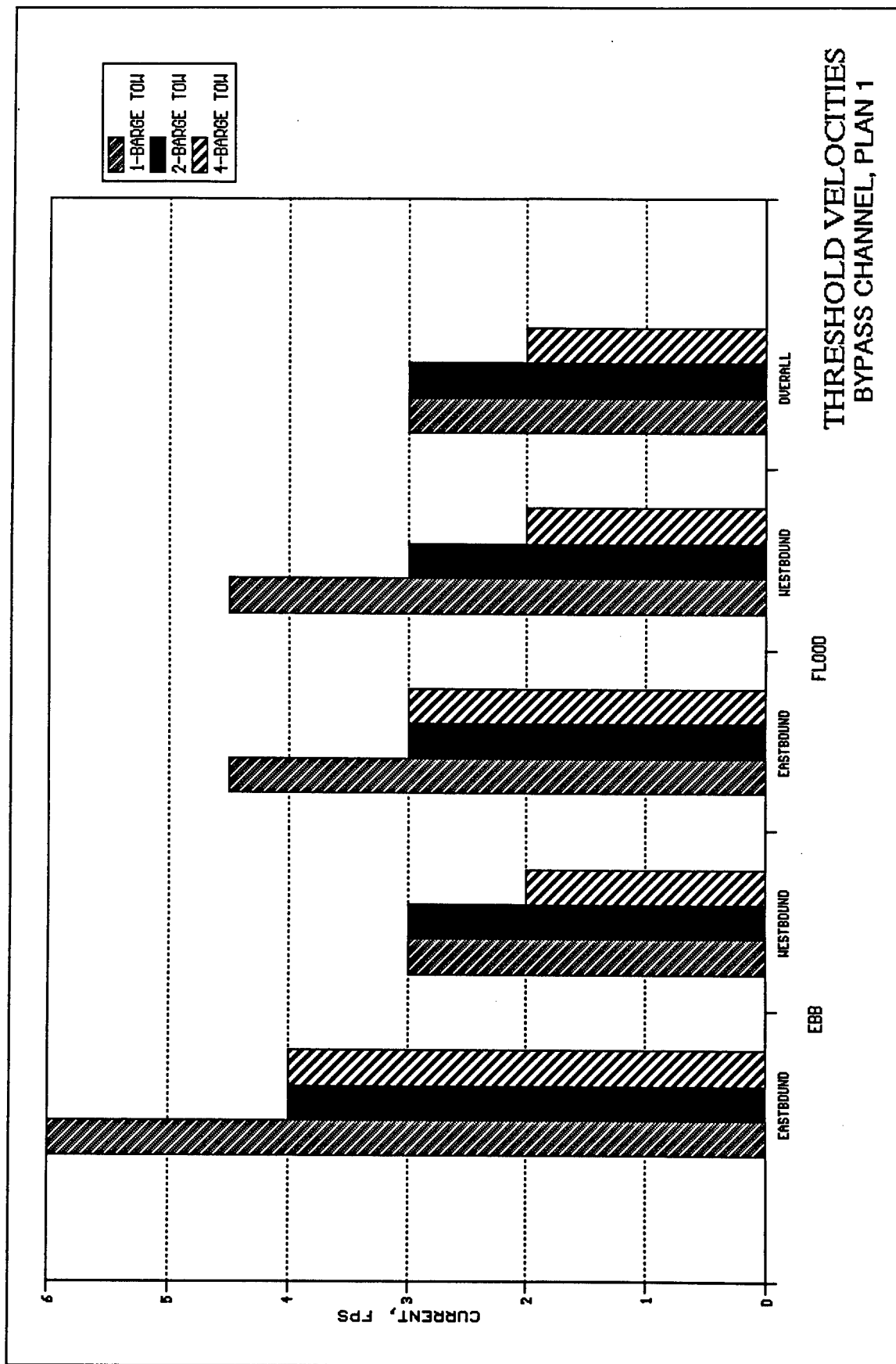


Plate 38







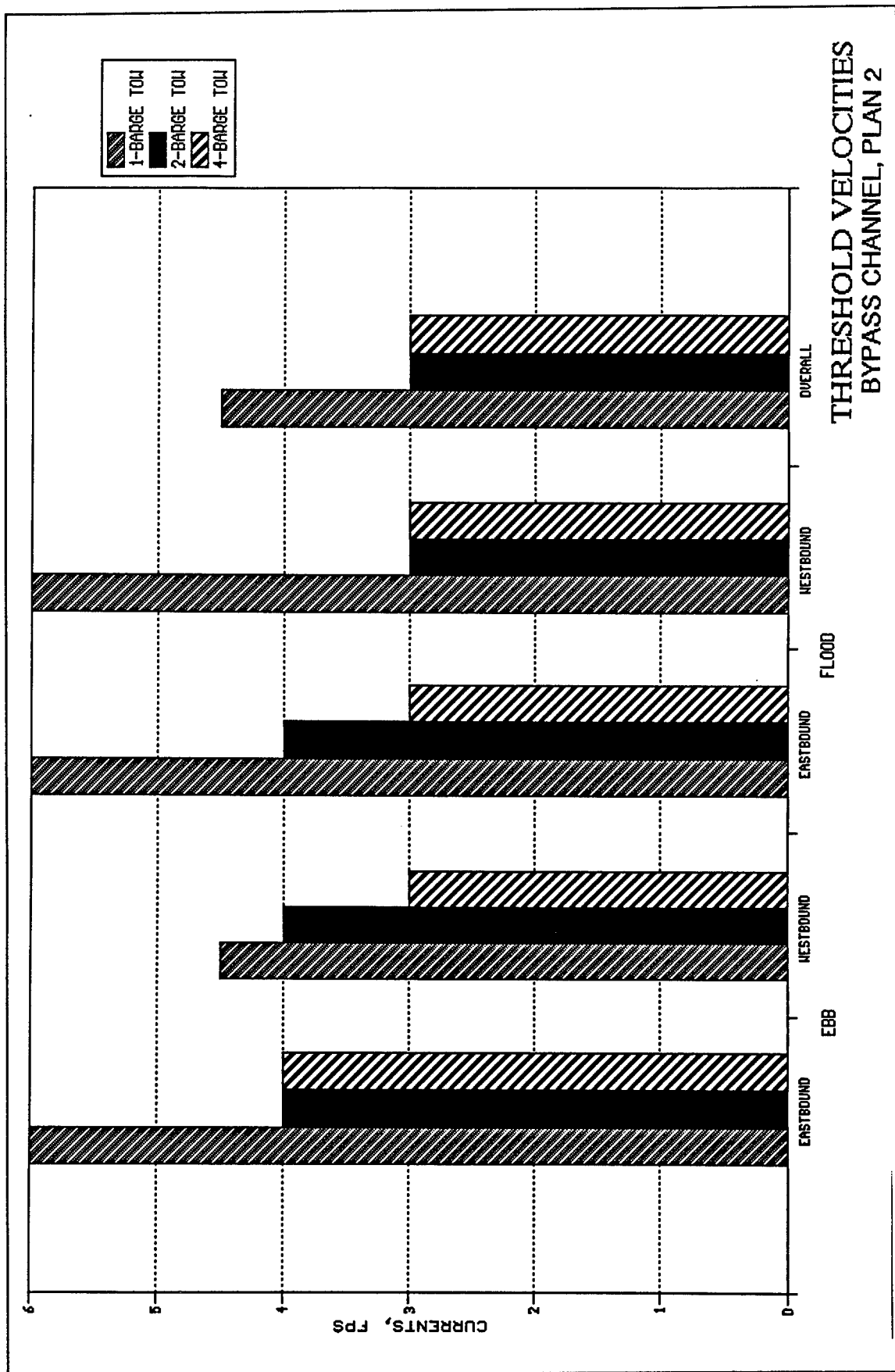
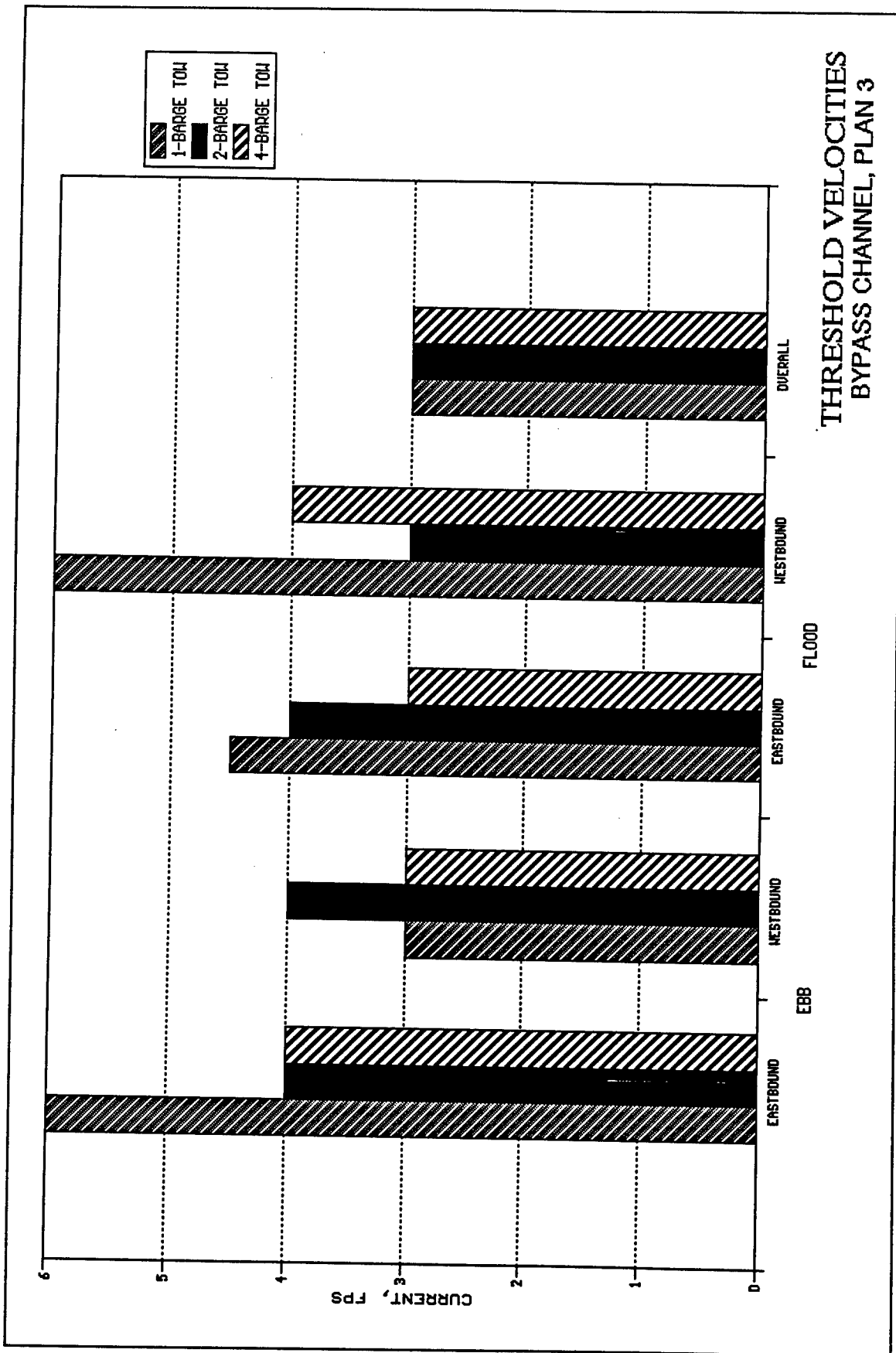


Plate 42



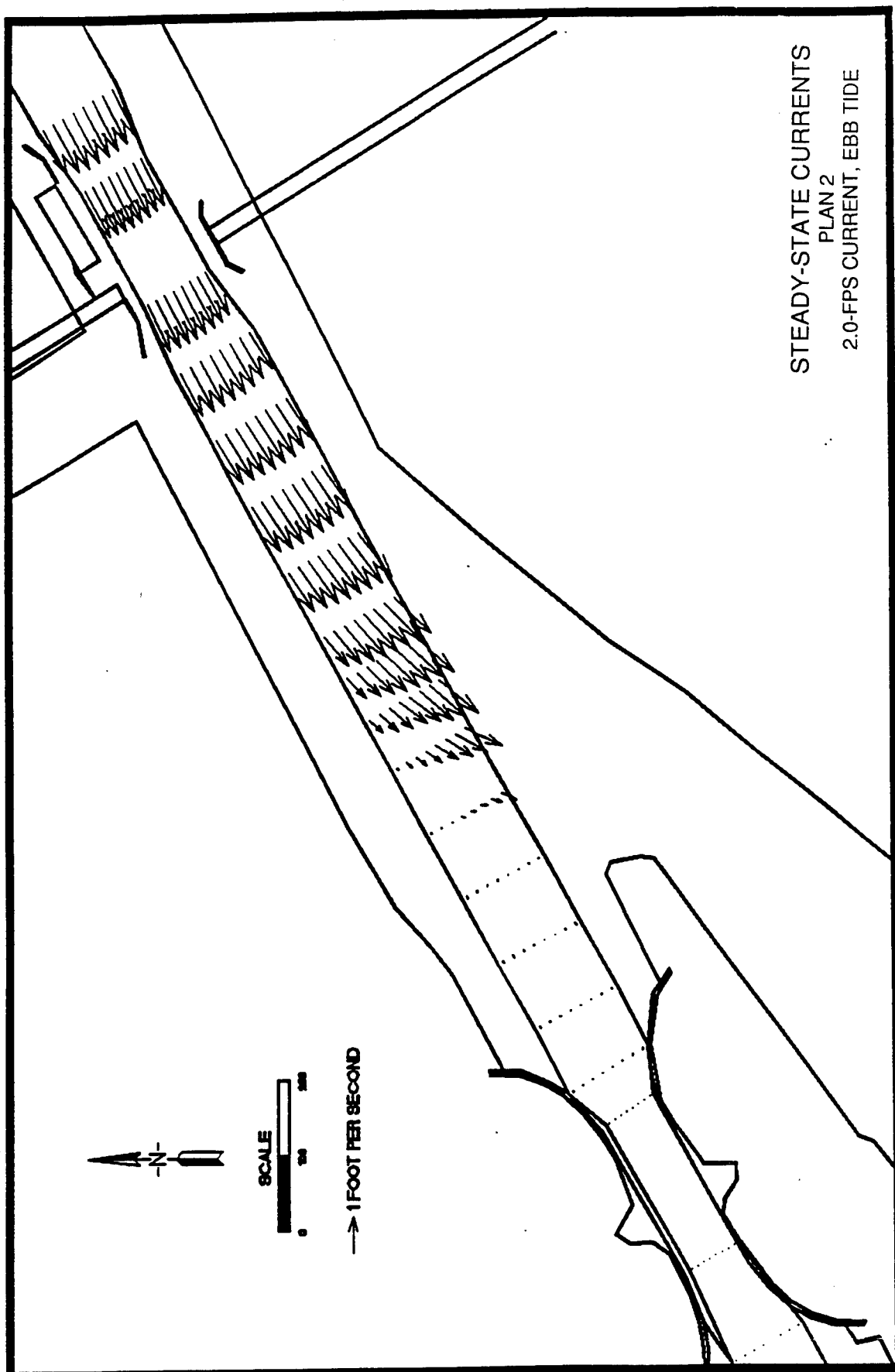
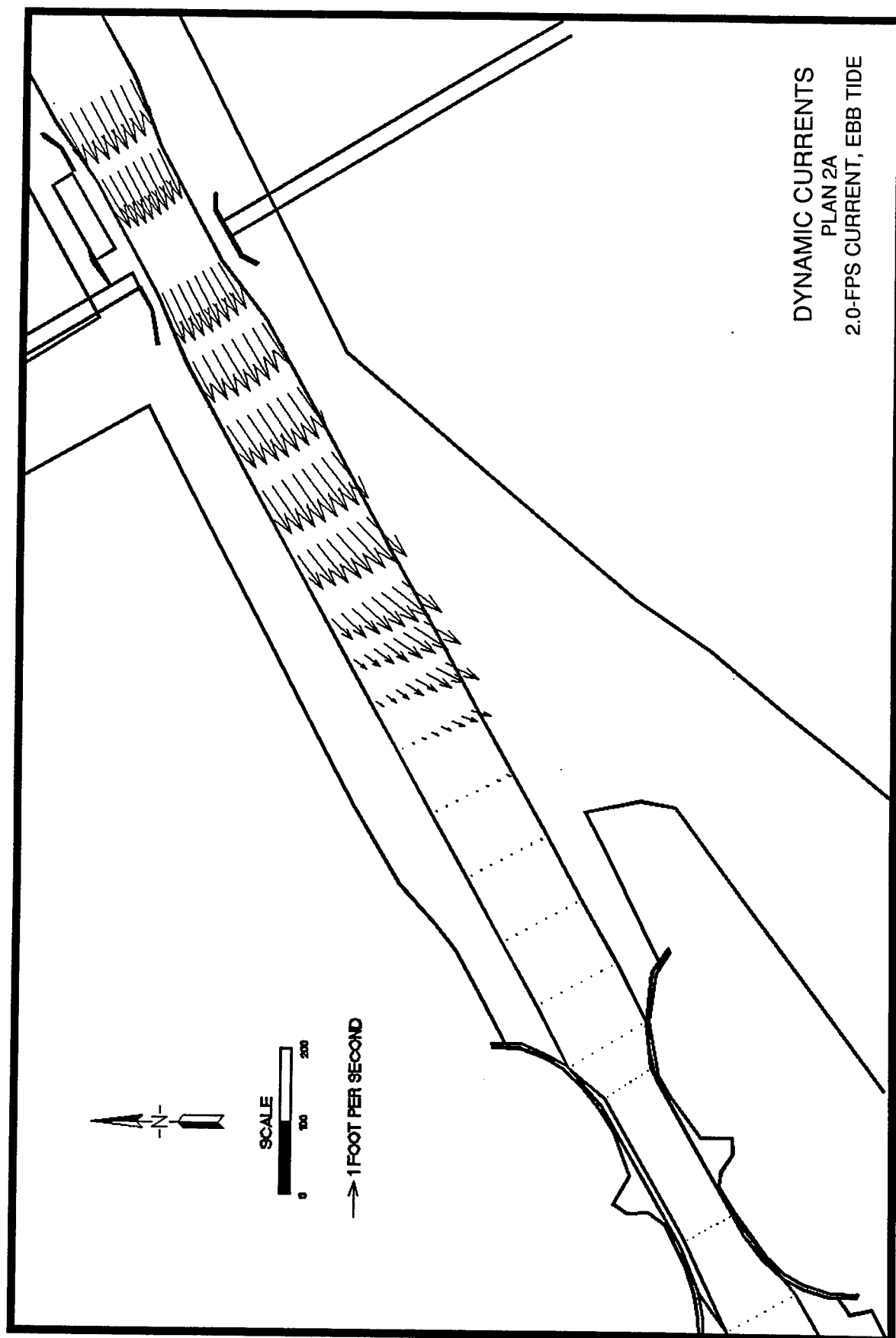


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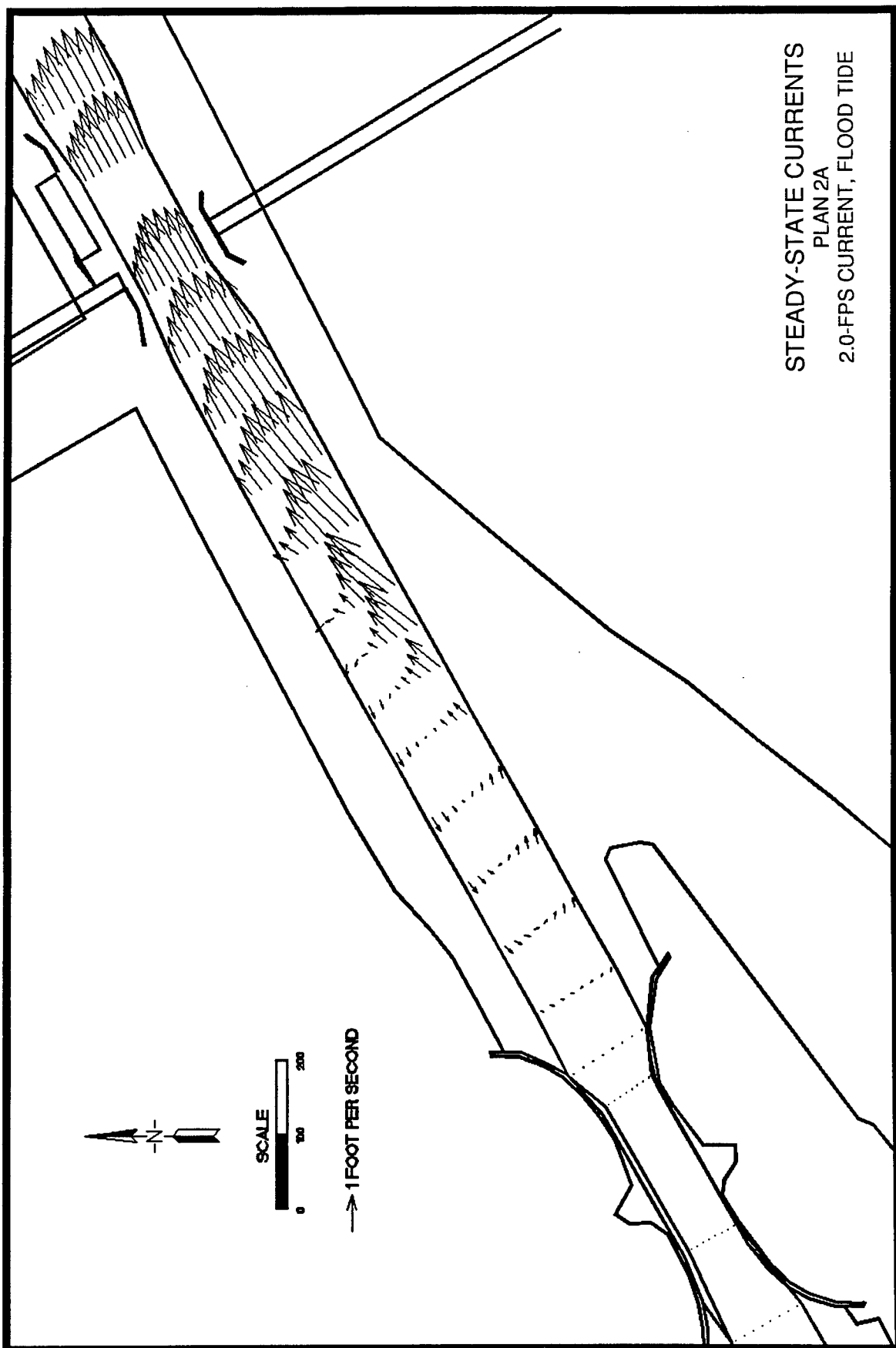


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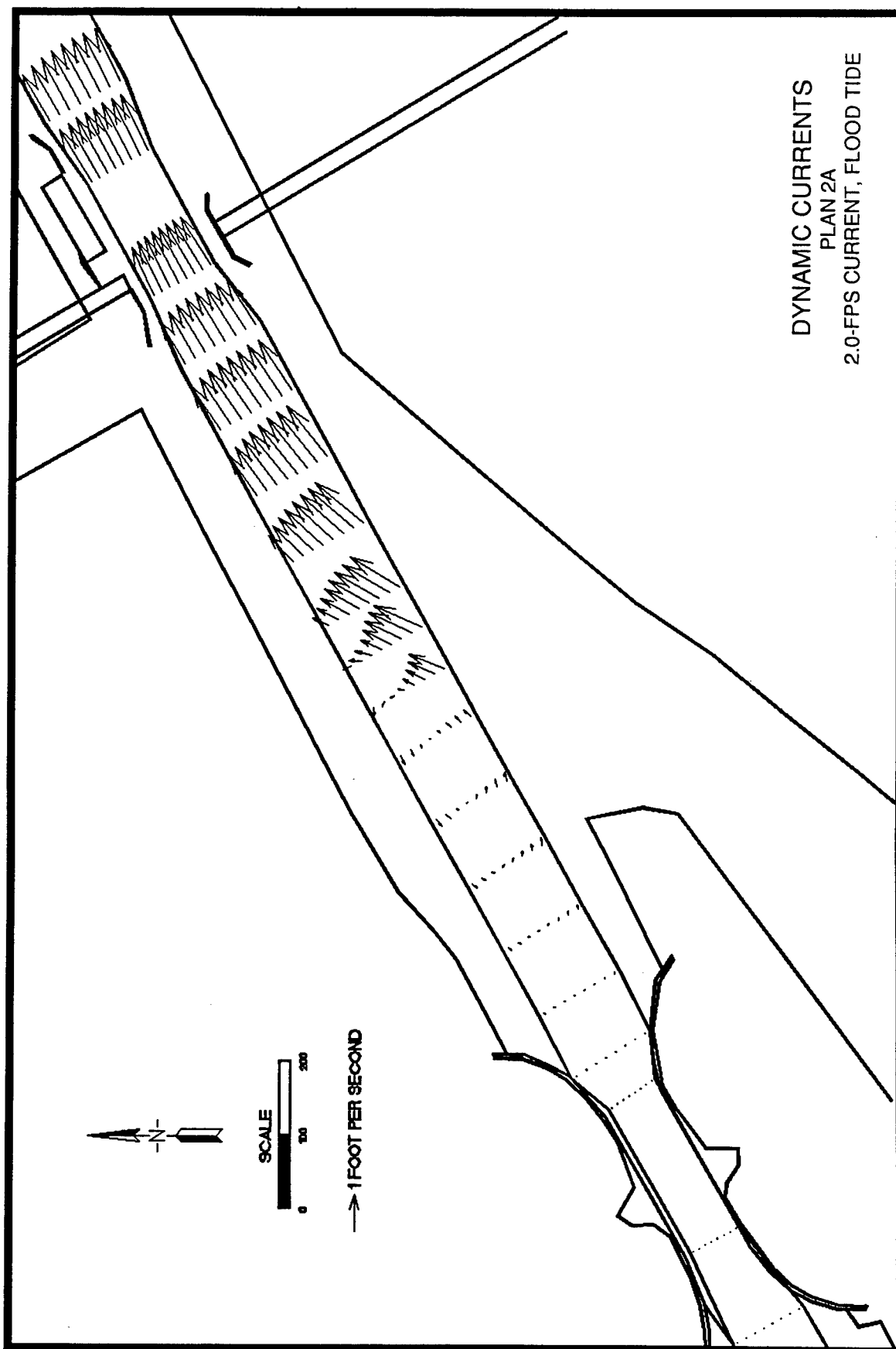


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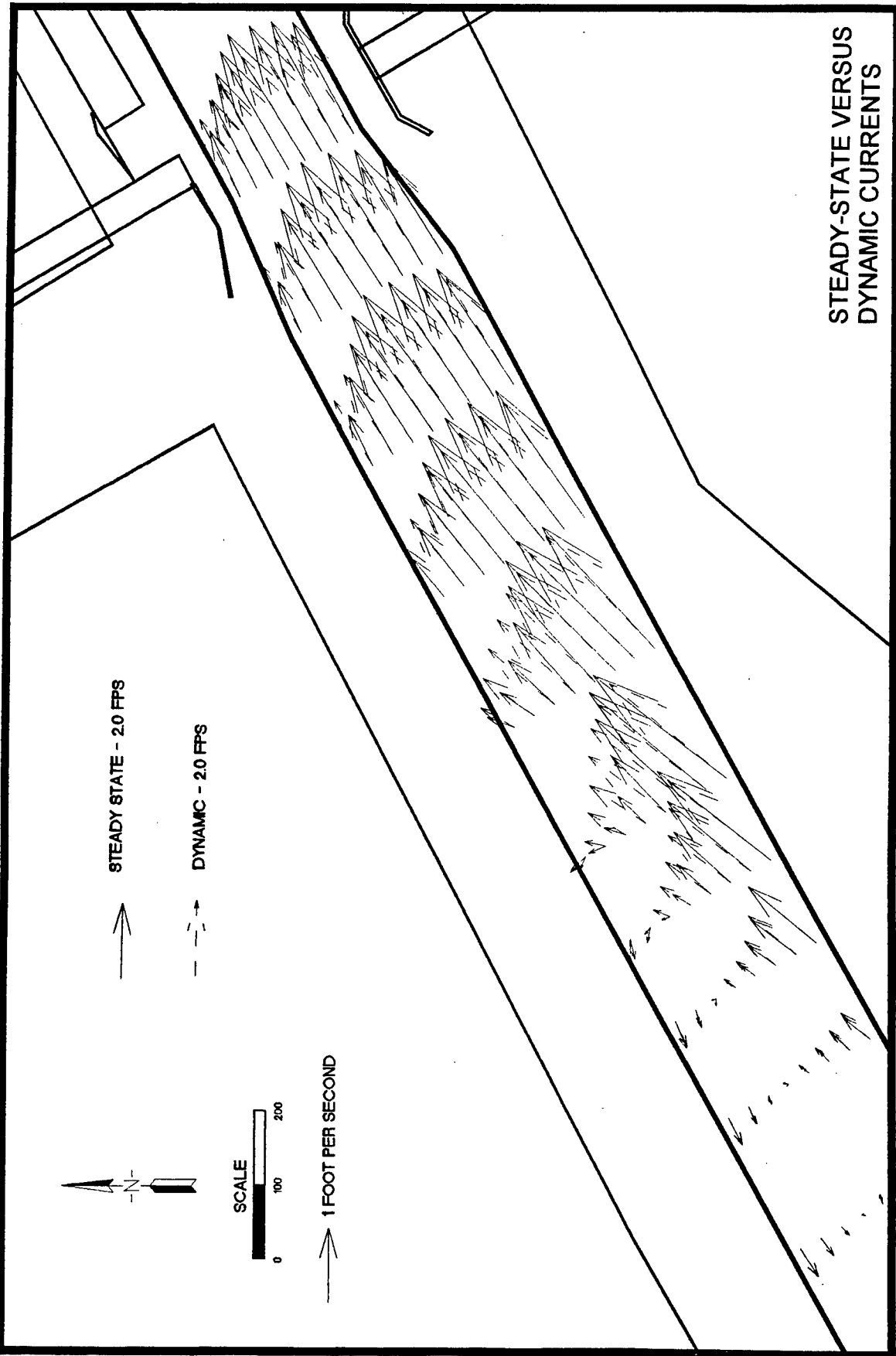
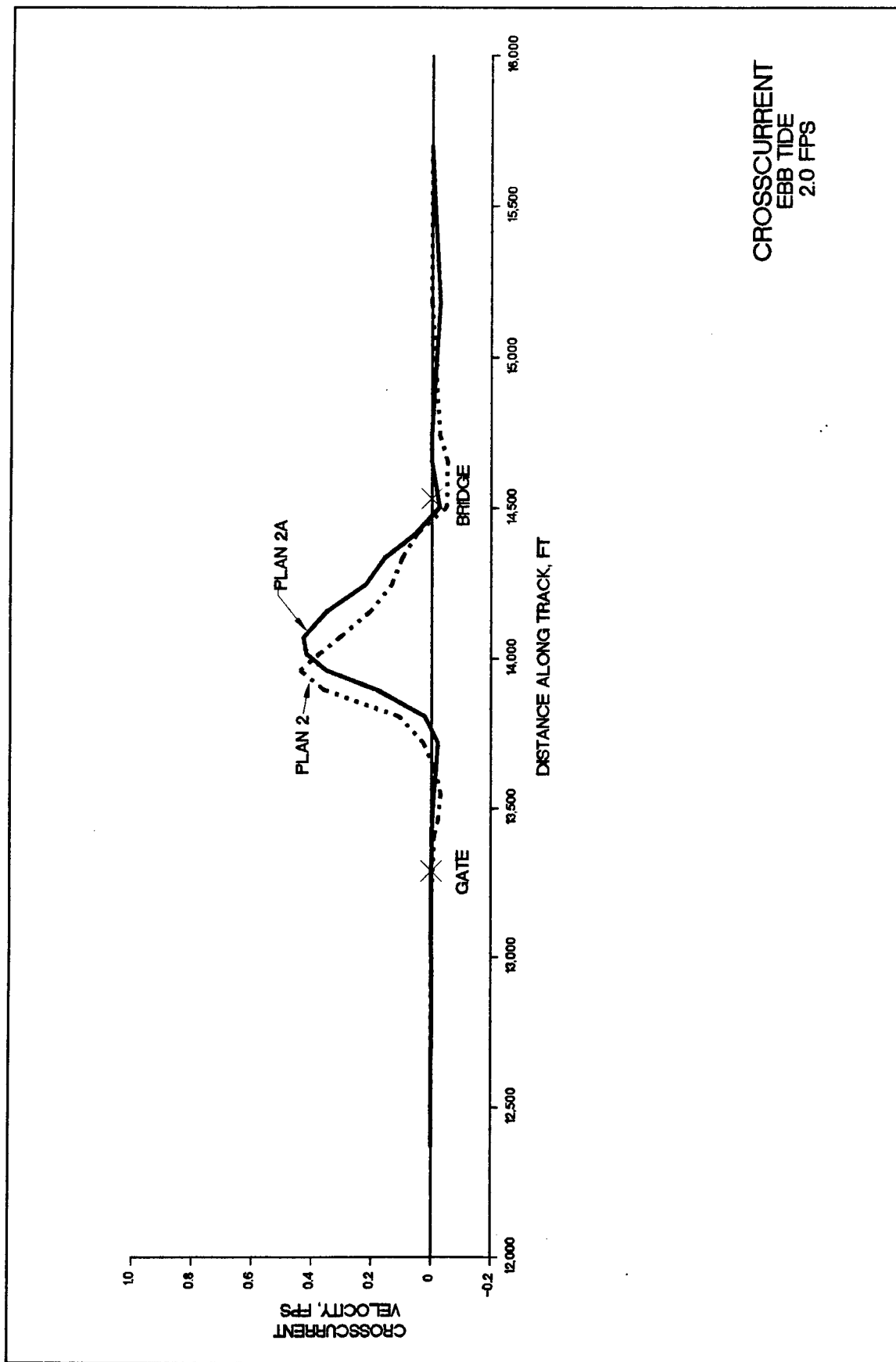
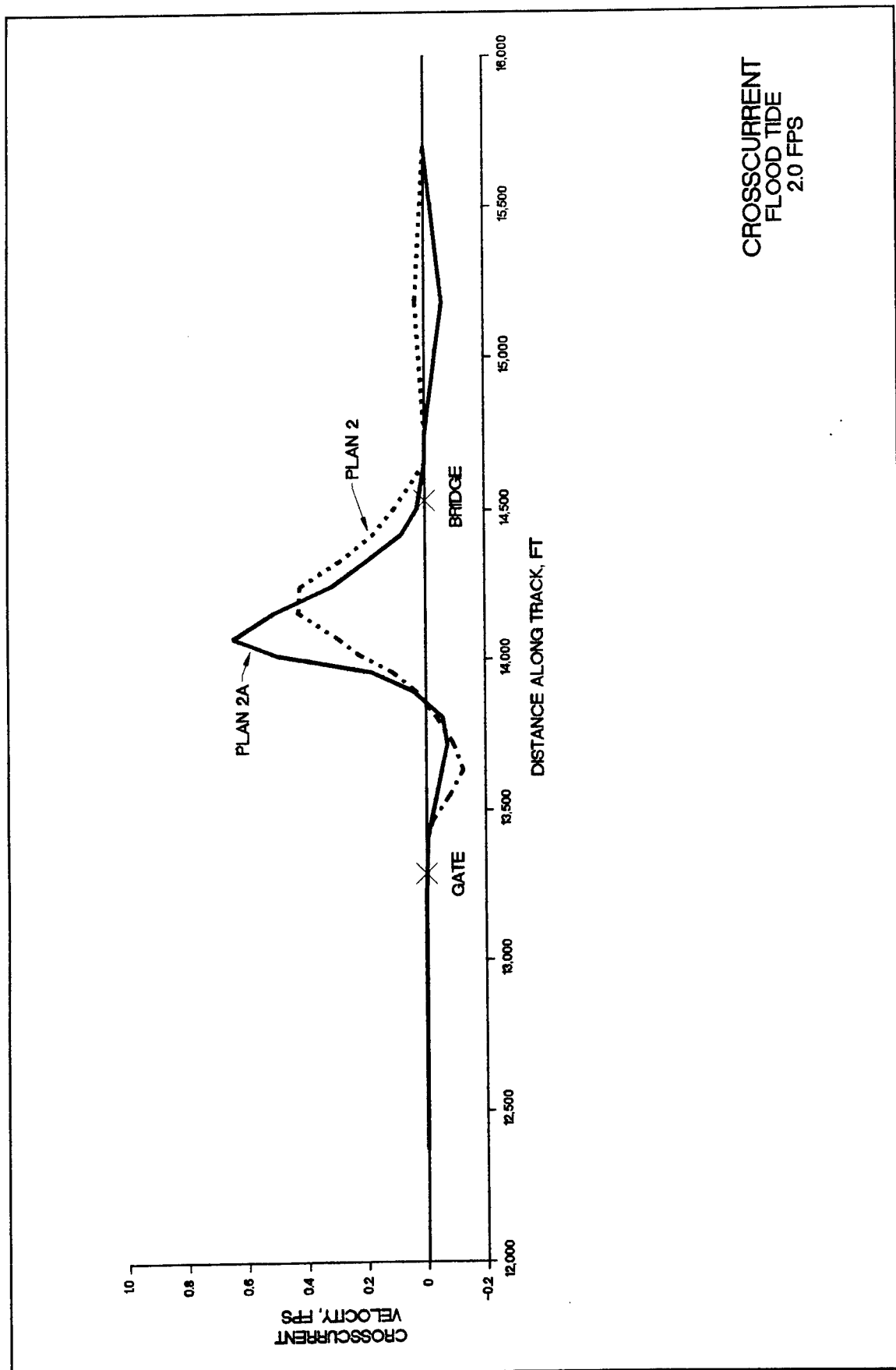
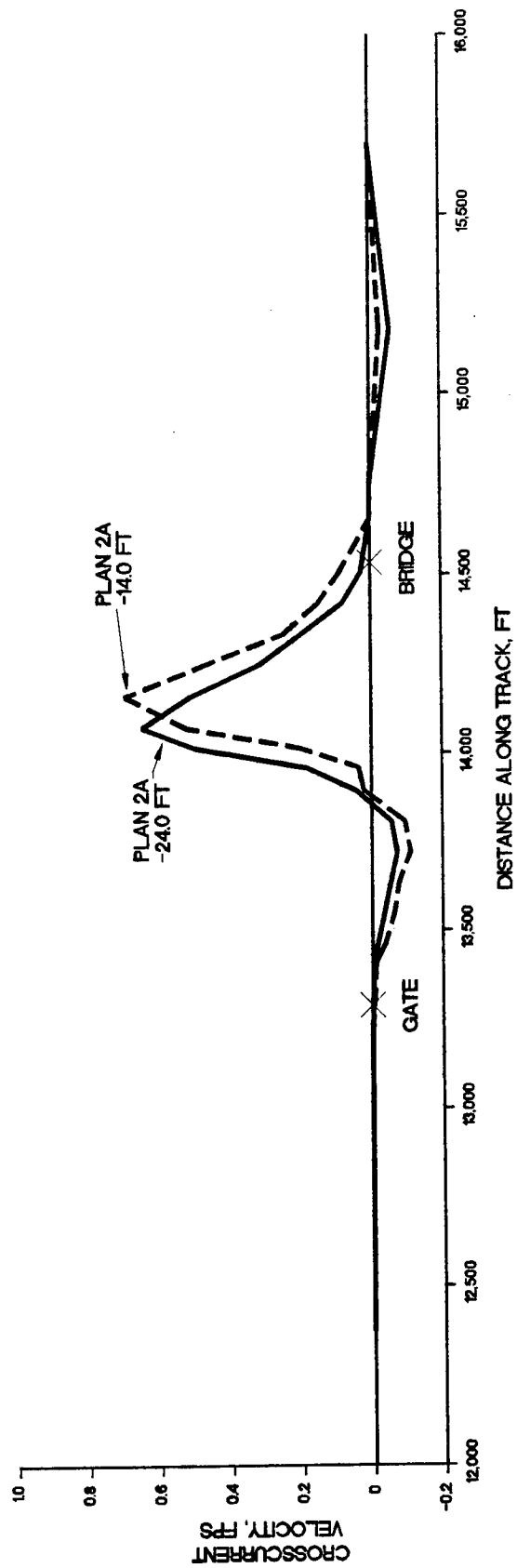


Plate 48







CROSSCURRENTS
FLOOD TIDE
2.0 FPS
ELEVATIONS -24.0 FT AND -14.0 FT

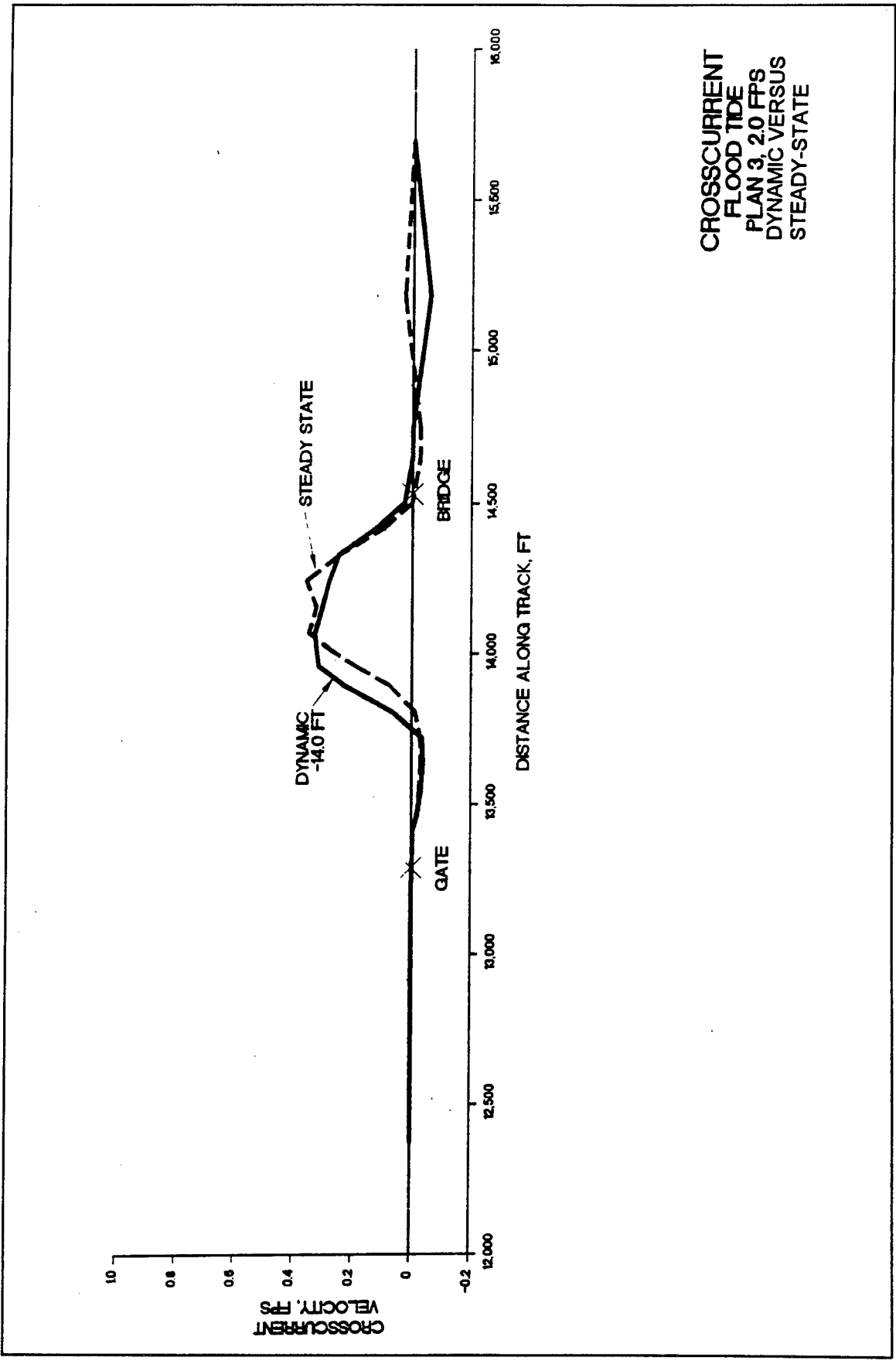
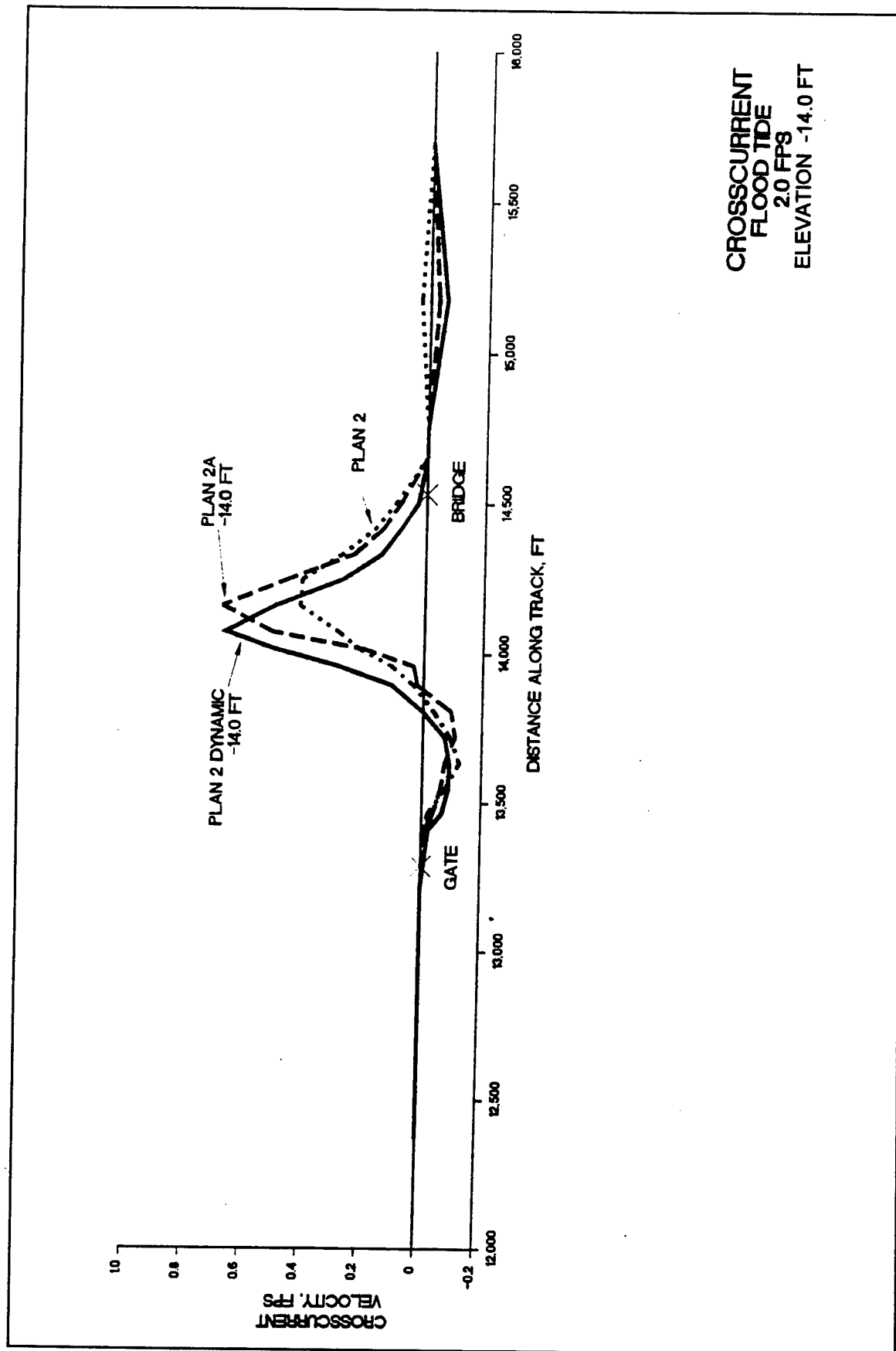


Plate 52



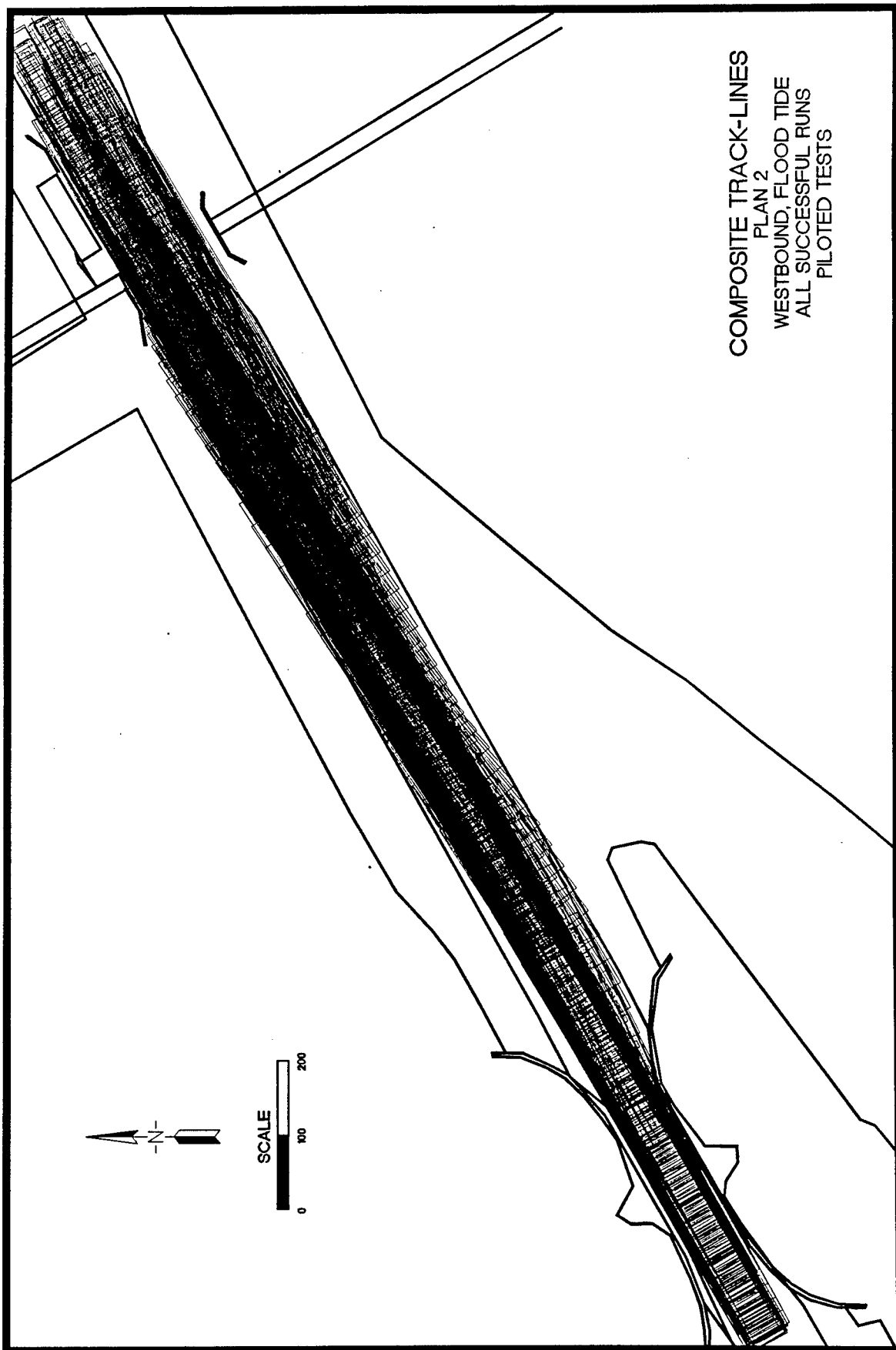
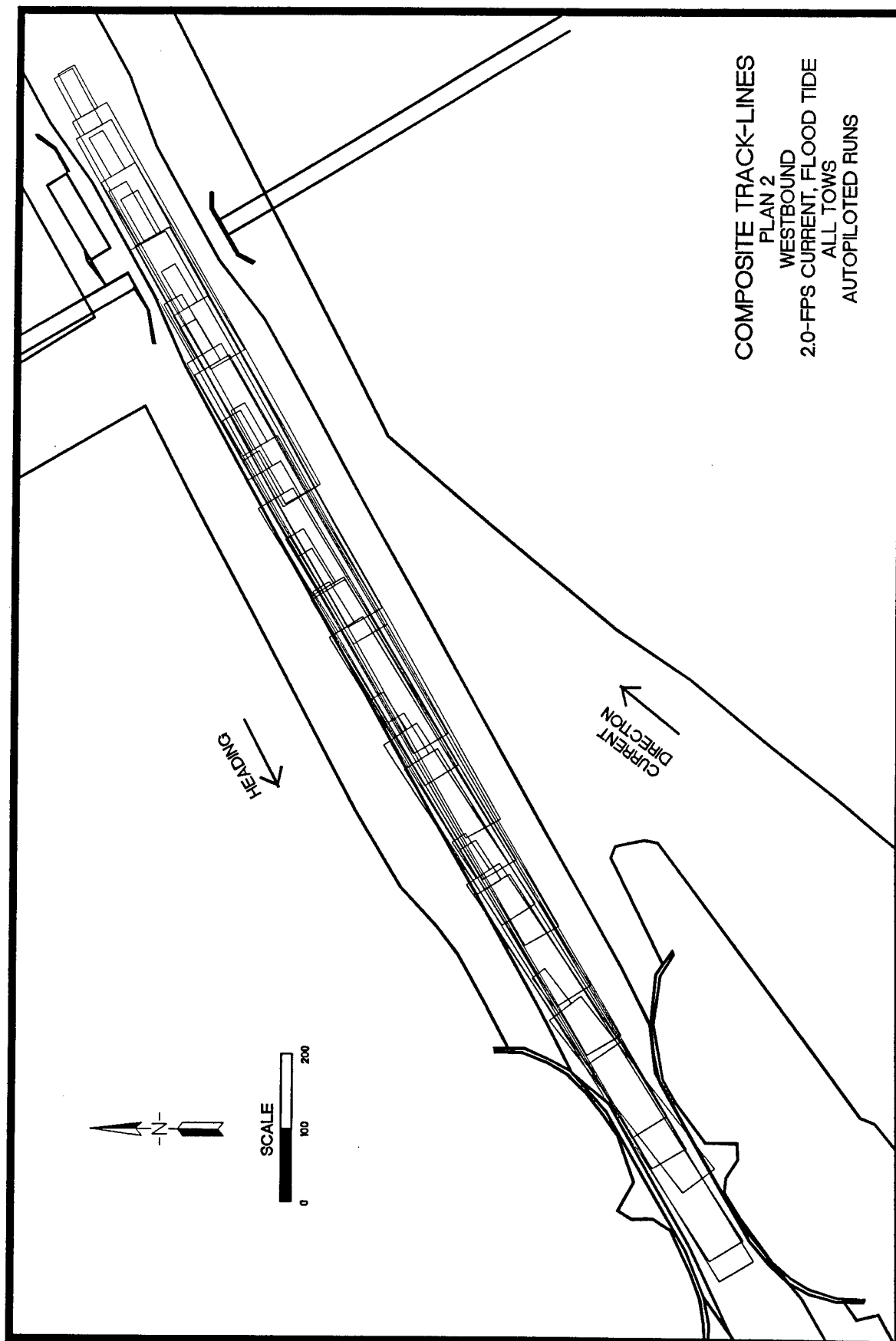


Plate 54



COMPOSITE TRACK-LINES
PLAN 2
WESTBOUND
2.0-FPS CURRENT, FLOOD TIDE
ALL TOWS
AUTOPILOTED RUNS

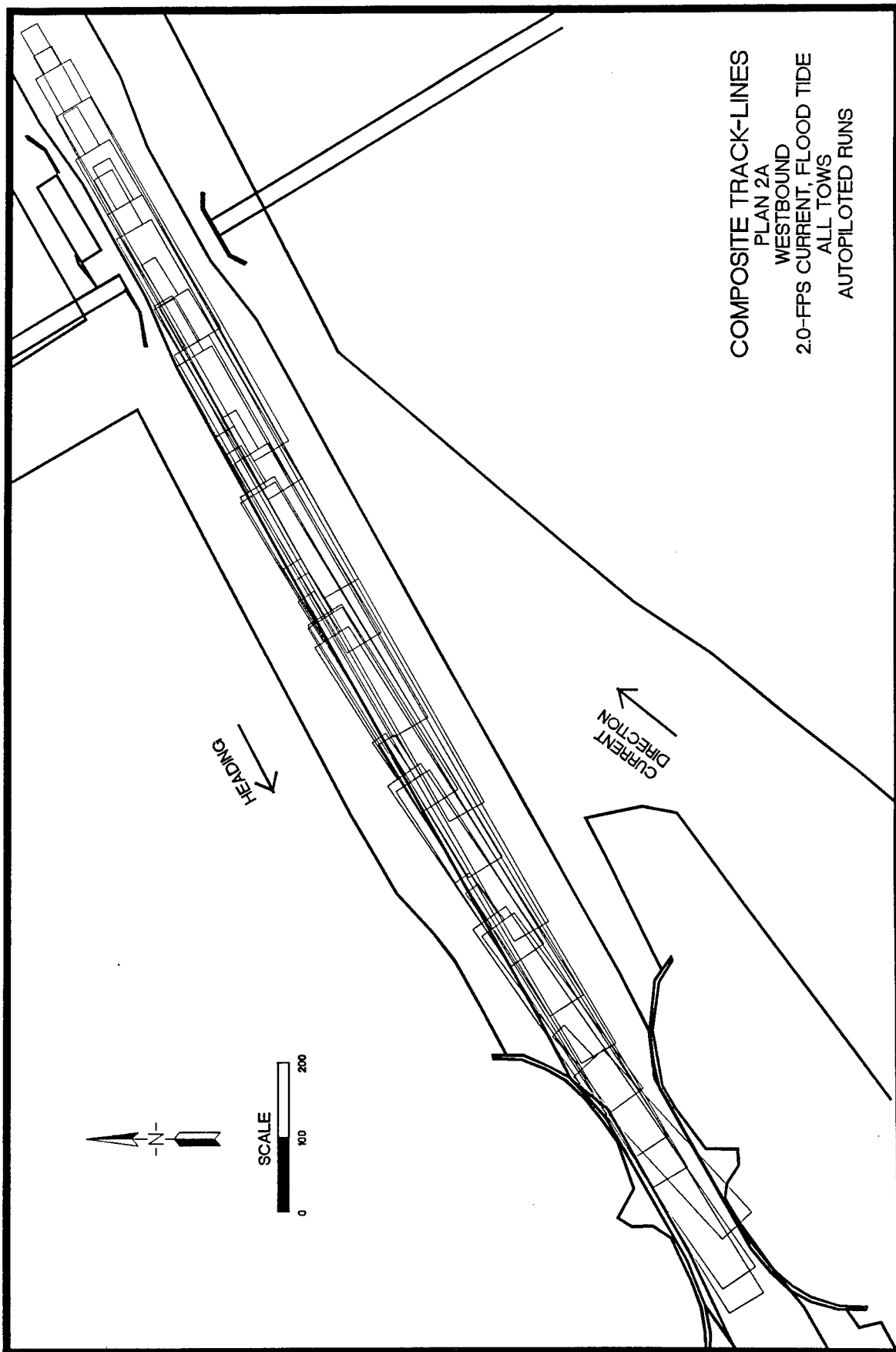
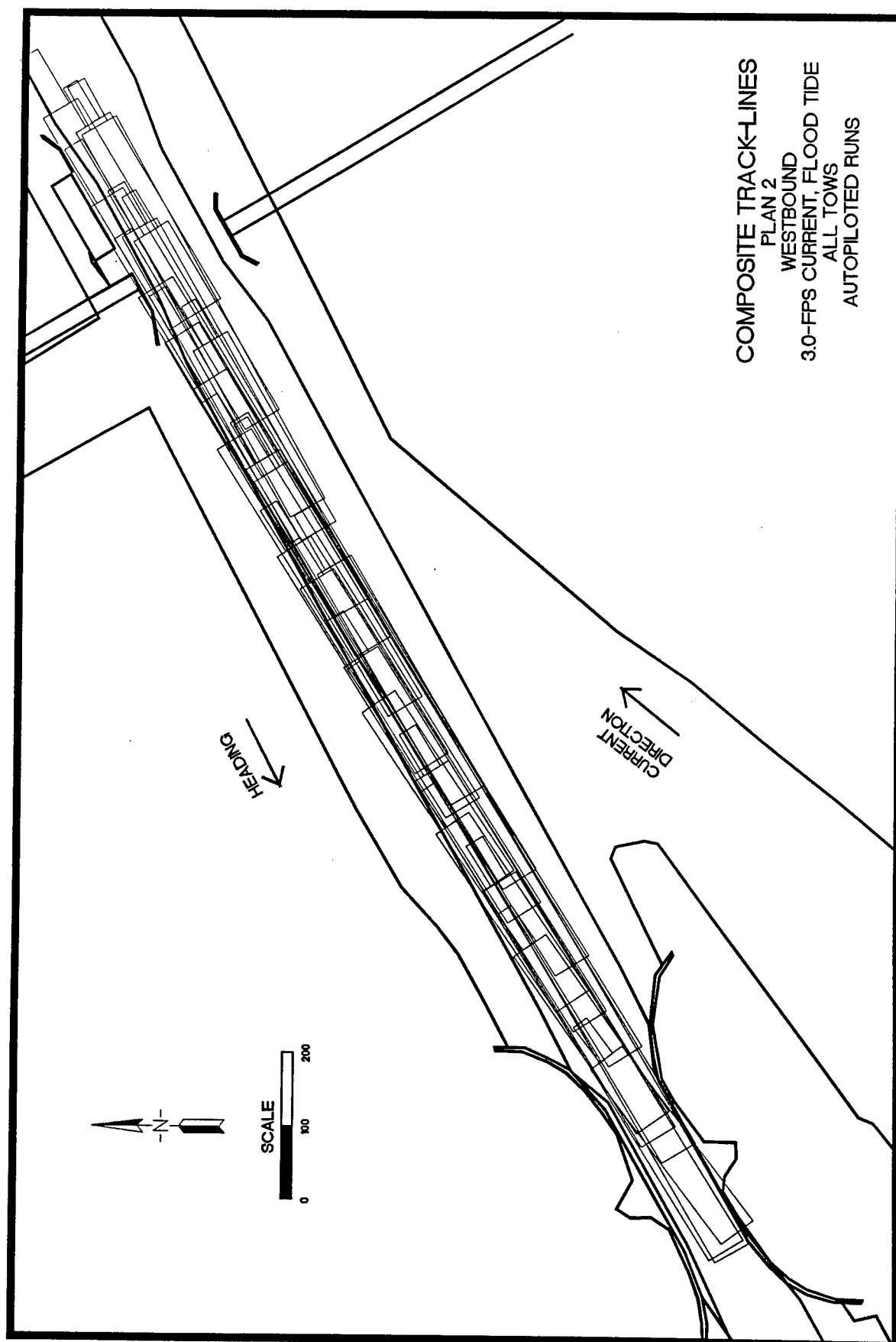
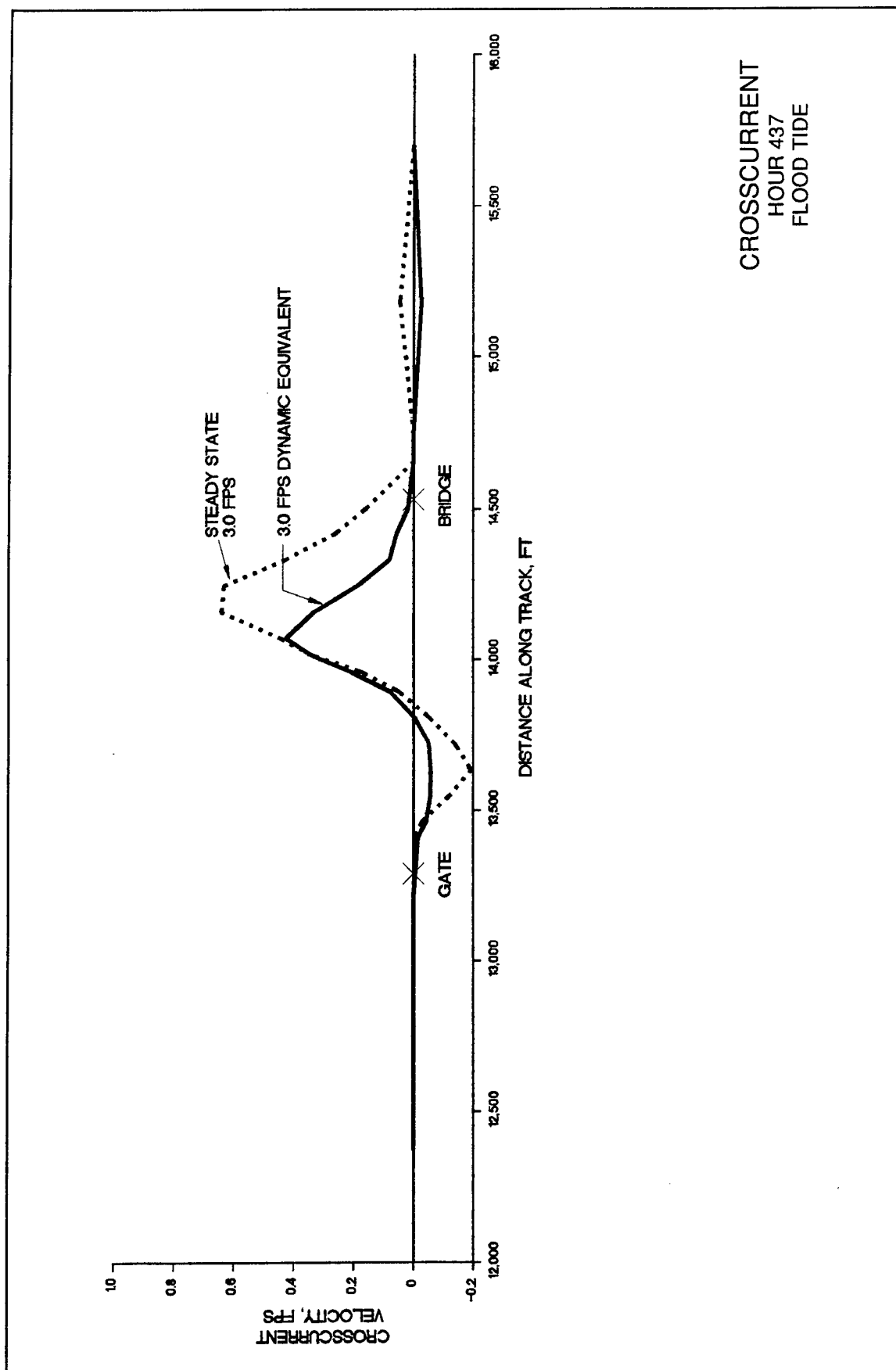
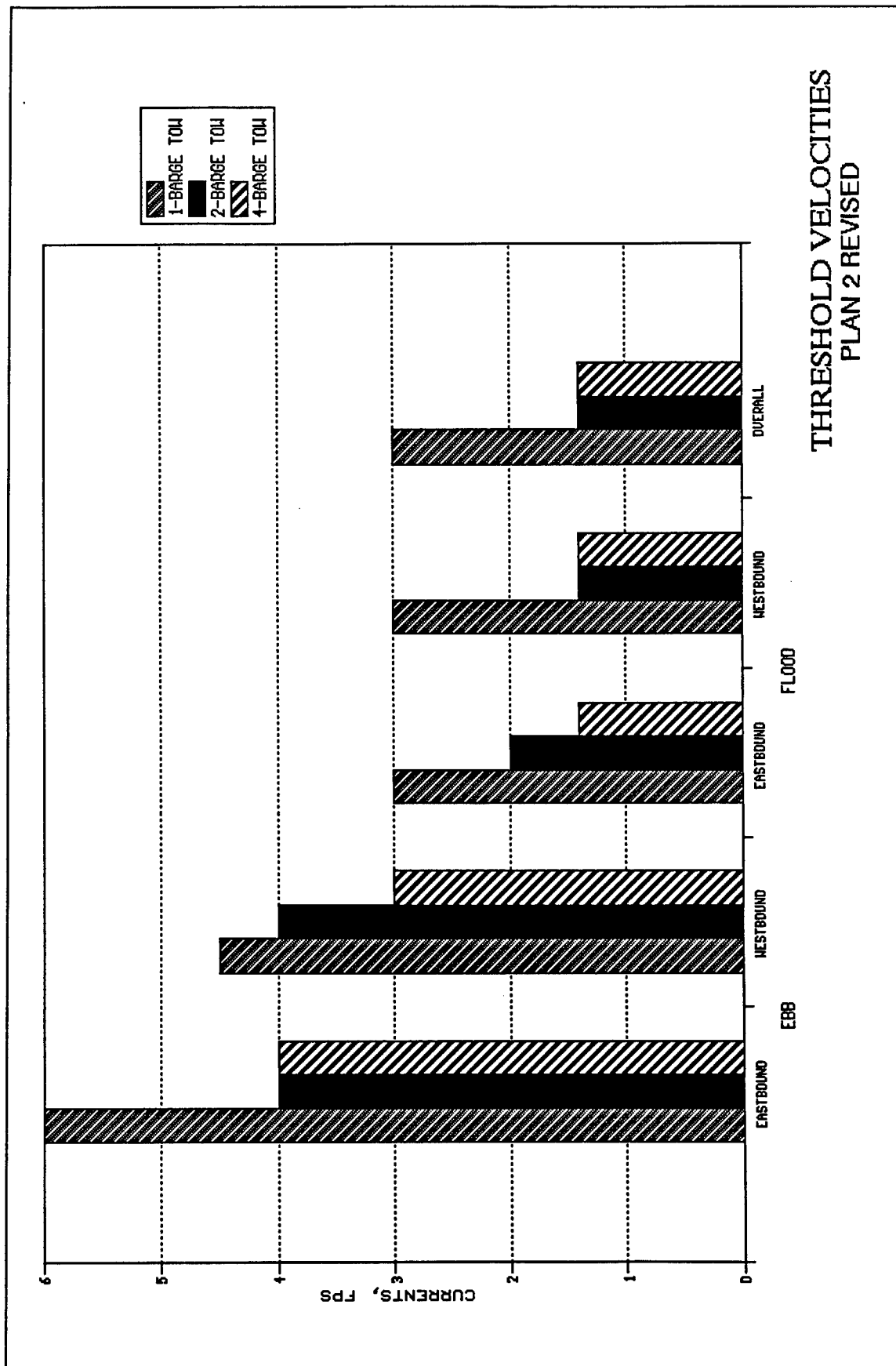
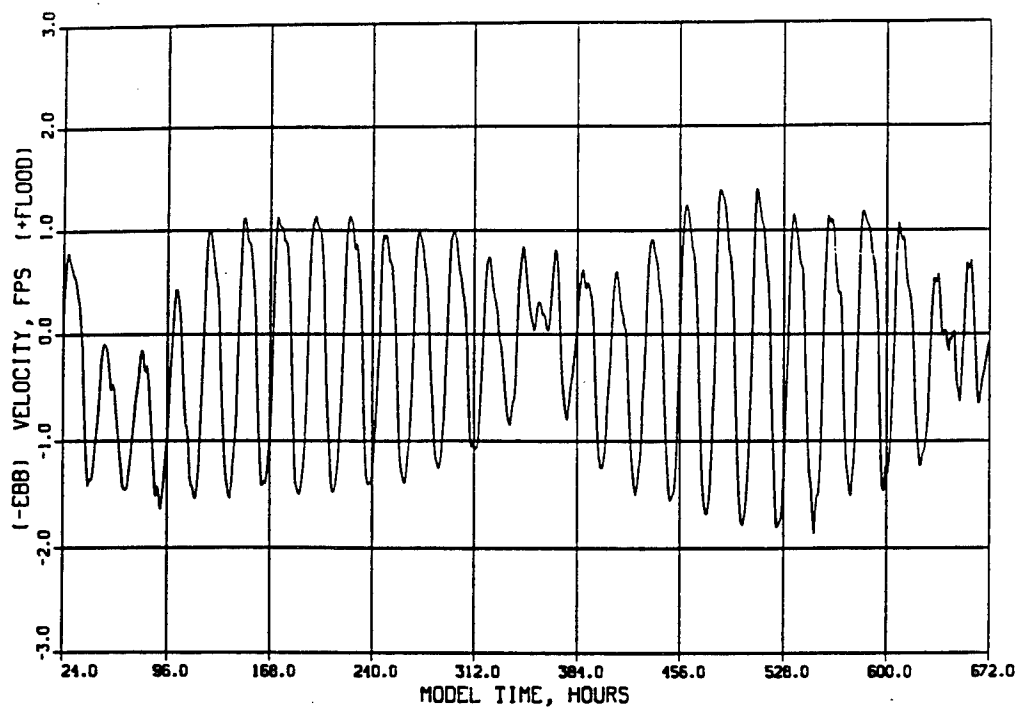


Plate 56

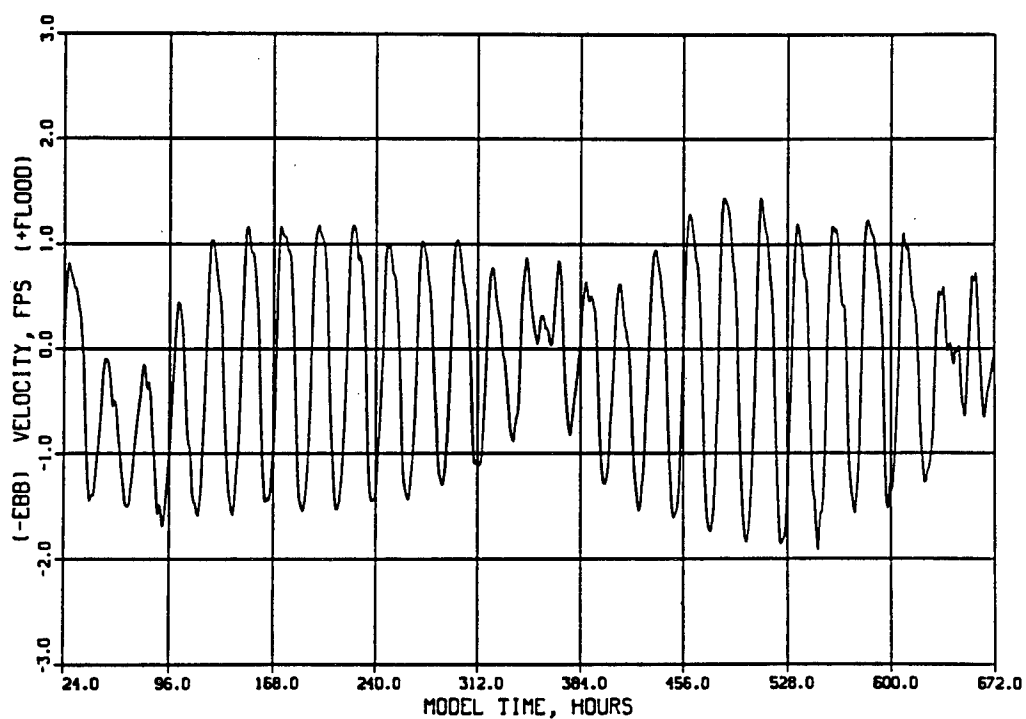








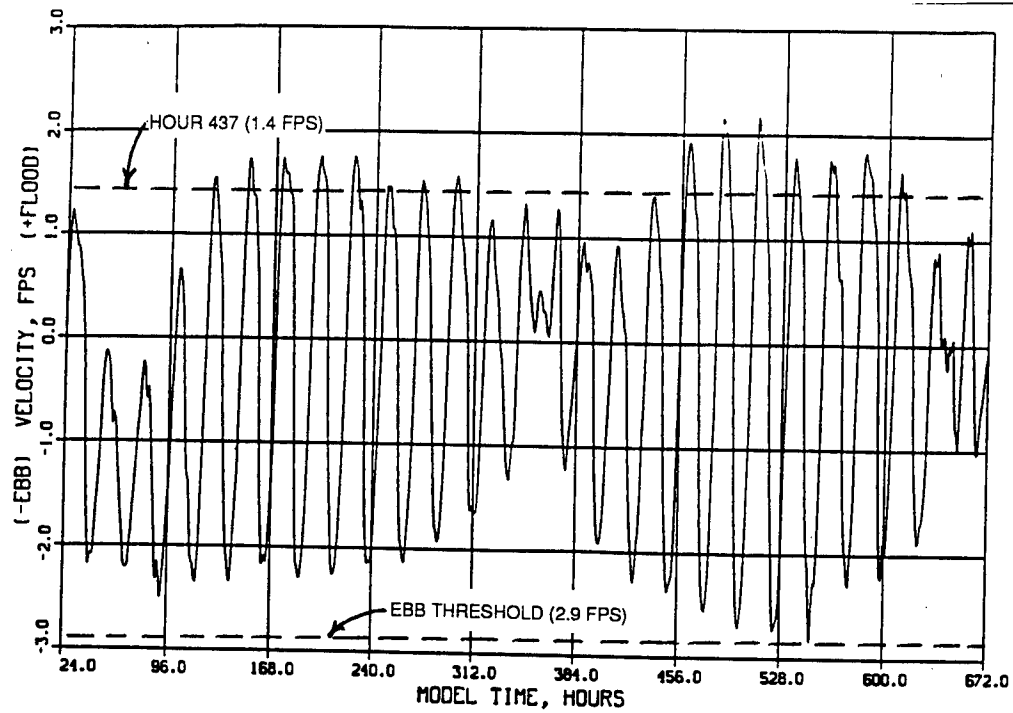
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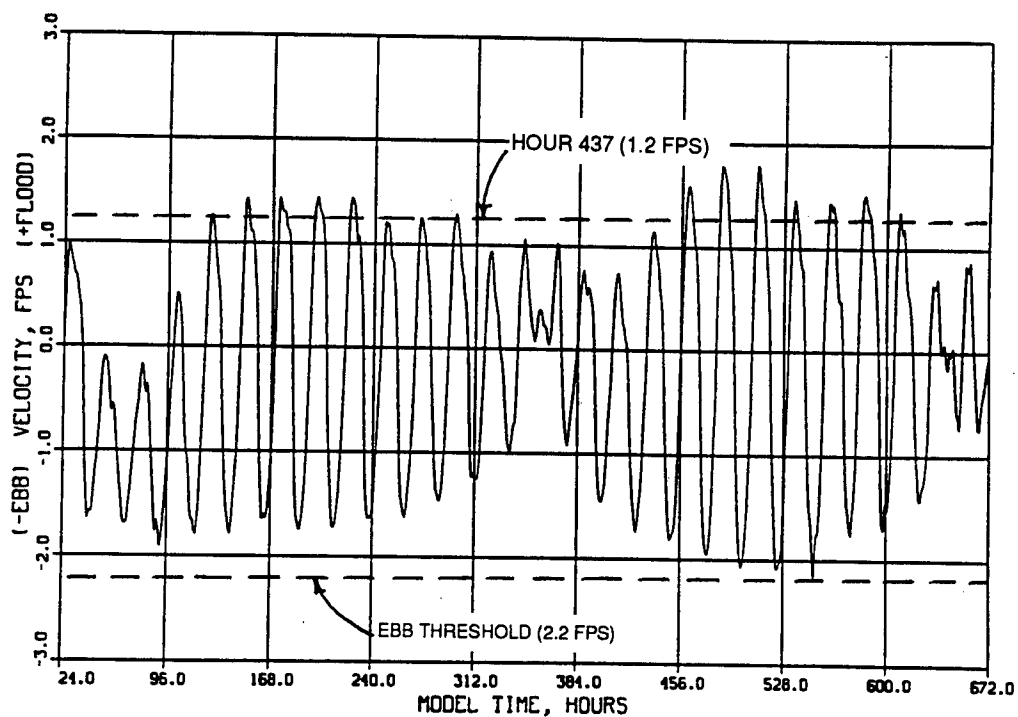
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— RMA-2V

RMA-2V RESULTS
NAVIGATION BYPASS CHANNEL DESIGN 3
27-DAY SIMULATION
NODES 3205, 861



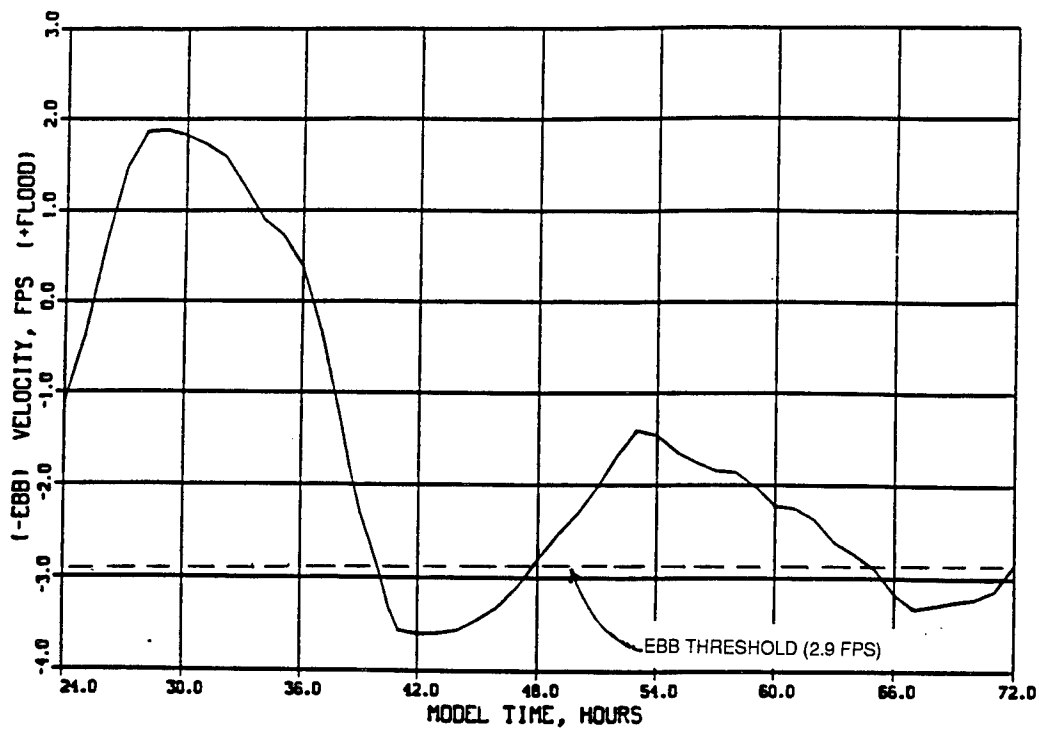
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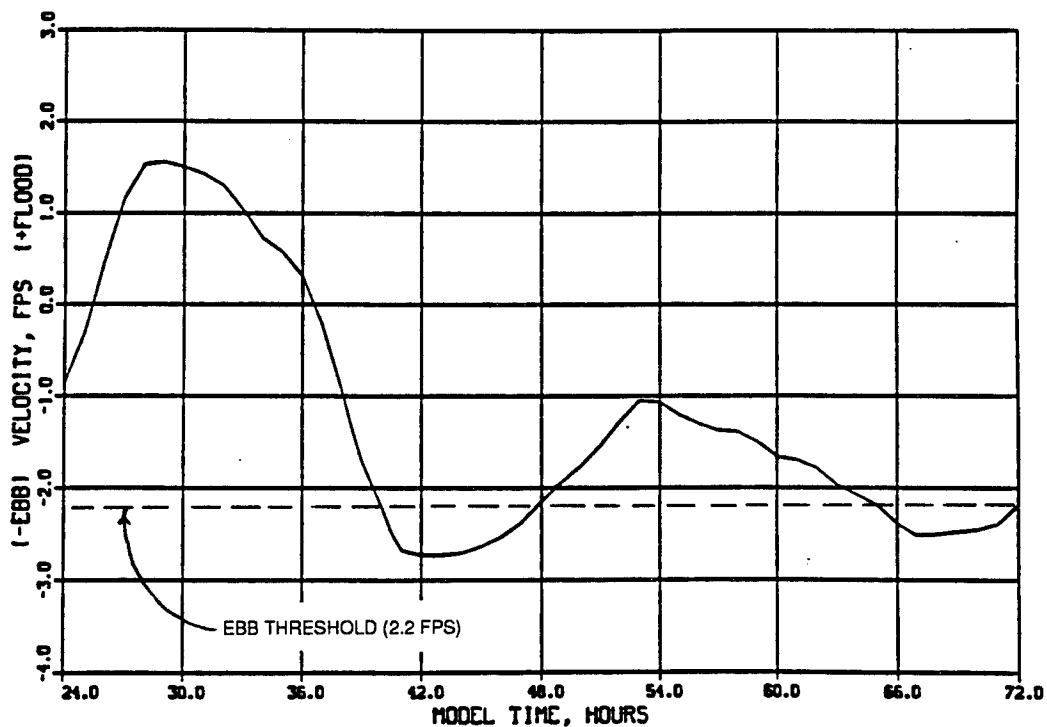
NODE 830

LEGEND
— RMA-2V

RMA-2V RESULTS
NAVIGATION BYPASS CHANNEL DESIGN 2
27-DAY SIMULATION
NODES 2811, 830



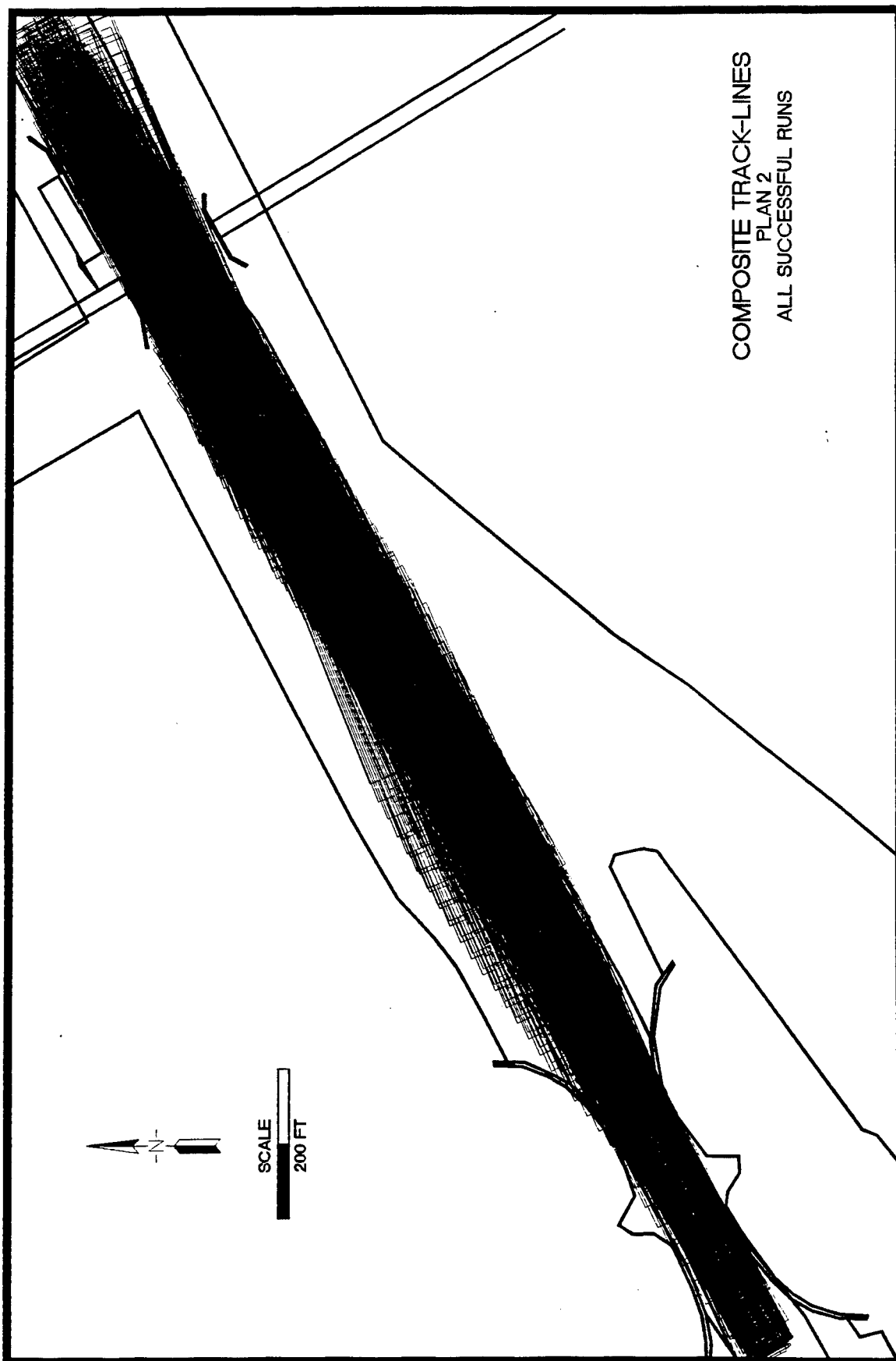
NODE 2811



NODE 830

LEGEND
— RMA-2V

RMA-2V RESULTS
FRONTAL PASSAGE
HIGH AMPLITUDE (TROPIC) TIDE
MODEL HOURS 24-72
NODES 2811, 830



REPORT DOCUMENTATION PAGE

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13. ABSTRACT (Maximum 200 words) <p>At one time, the Colorado River flowed across the Gulf Intracoastal Waterway (GIWW) into the Gulf of Mexico. A project to divert the freshwater riverflows into West Matagorda Bay is under construction. Its main objective is to increase the productivity of the bay. The project includes a diversion dam to be located on the present Colorado River and a rerouted navigation bypass channel to allow access from the GIWW to the Gulf. The navigation bypass channel outlet will join the GIWW between the eastern lock and a floating pontoon bridge on Route 2031.</p> <p>A tow simulation study to address the navigation issues raised by industry was conducted on the ship simulator at the U.S. Army Engineer Waterways Experiment Station. The study included simulations of the crosscurrents from the Colorado River with and without the diversion channel, as well as the tidal currents from three proposed navigation bypass channels. The study had three purposes. One was to determine if the diversion of the riverflow into the channel to Matagorda Bay will have a negative impact on tows crossing the Colorado River between the locks. The second purpose was to determine whether tidal flows may cause navigation problems for GIWW traffic in the vicinity of the navigation bypass channel. The third purpose was to determine at what frequency critical flow conditions will occur and develop operating procedures to minimize the impacts of these critical flows. The investigation was conducted in two</p> <p style="text-align: right;">(Continued)</p>				
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phases to determine (a) the safe operational limits of crosscurrent conditions, and (b) the length of time during cycles that these limits are exceeded.

The maximum current velocity at which the towboat captains can make a successful run, the threshold velocity, was the same for the preconstruction and postconstruction river intersections. The captains rated the postconstruction river only slightly more difficult than the preconstruction river. Therefore, it was concluded that the implementation of the diversion of the Colorado River will not hinder navigation of the river intersection.

Of the three navigation bypass channel designs tested, the one recommended in the project's General Design Memorandum (GDM) had the lowest threshold velocities. This means that it had the largest adverse impact on navigation. The other two bypass channels tested had similar threshold velocities; however, the design that widened the intersection with the GIWW to spread the flow produced adverse bank effects. Therefore, the design in which the channel intersected more parallel to the GIWW was selected as the best design.

After completion of the dynamic current calculations, it was determined that the ebb current will not create any delays from astronomical tide conditions. However, intermittent, multihour delays may be expected during cold front passages. The delays caused by flood tide could be as much as 15 percent of a 28-day period.

It is recommended that a guide wall be added to the lock on the GIWW north of the intersection of the bypass channel in the final project. Monitoring gages should be installed in both the navigation bypass channel and the Colorado River upstream of the GIWW. This will allow the lock personnel to advise tow captains of adverse flow conditions.

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